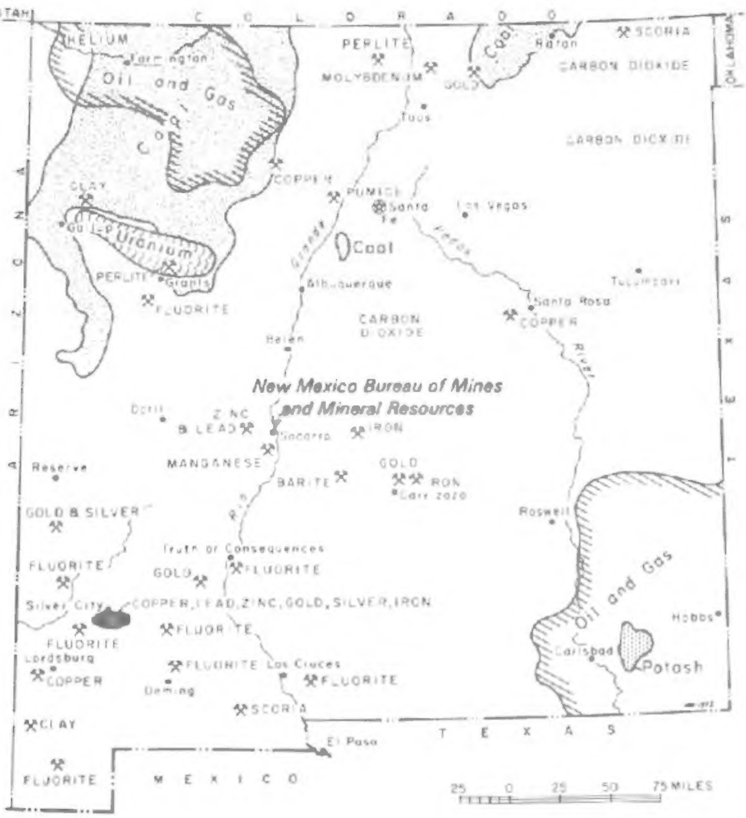
Mineral and Water Resources of New Mexico

Prepared by:
U.S. Geological Survey for the U.S. Senate Committee on Interior and Insular Affairs

In cooperation with:
New Mexico Bureau of Mines and Mineral Resources
New Mexico Oil Conservation Commission
New Mexico State Engineer
U.S. Bureau of Mines



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COMMITTEE PRINT

MINERAL AND WATER RESOURCES OF NEW MEXICO

REPORT

PREPARED BY THE

UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

THE

NEW MEXICO STATE ENGINEER OFFICE

AND THE

NEW MEXICO OIL CONSERVATION COMMISSION

AT THE REQUEST OF

SENATOR CLINTON P. ANDERSON

OF NEW MEXICO

OF THE

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS UNITED STATES SENATE

Printed for the use of the Committee on Interior and Insular Affairs

U.S. GOVERNMENT PRINTING OFFICE

41-737O WASHINGTON : 1965

MEMORANDUM FROM THE CHAIRMAN

To *Members of the Senate Committee on Interior and Insular Affairs:*

I am transmitting for your information a report entitled "Mineral and Water Resources of New Mexico," prepared by the U.S. Geological Survey at the request of our colleague, Senator Clinton P. Anderson.

This detailed survey will be particularly helpful to government and business leaders in New Mexico. It will also be valuable to the Congress and members of this committee as we consider legislation regarding mineral and water development.

HENRY M. JACKSON, *Chairman.*

FOREWORD

This report, was prepared at my request by the U.S. Geological Survey in collaboration with the New Mexico Bureau of Mines and Mineral Resources, the New Mexico State Engineer Office and the New Mexico Oil Conservation Commission.

Its purpose is to make all significant data on New Mexico's important mineral and water resources available to interested citizens, to professional personnel in mining and water development, and to government., civic, and industrial leaders. I think that purpose has been well met.

I wish to thank all of those both in New Mexico and the Geological Survey who have contributed to the making of this report.

CLINTON P. ANDERSON.

MINERAL AND WATER RESOURCES OF NEW MEXICO

REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

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UNITED STATES SENATE

LETTER OF TRANSMITTAL

U.S. Department of the Interior,
Office of the Secretary,
Washington, D.C., January 13, 1965

Hon. Clinton P Anderson,
U.S. Senate,
Washington, D.C.

Dear Senator Anderson: We have forwarded to your office a summary report on the mineral and water resources of New Mexico, which was prepared in response to your request of July 8, 1964, to the Geological Survey.

The report was prepared by the Geological Survey in collaboration with the New Mexico Bureau of Mines and Mineral Resources, the New Mexico Oil Conservation Commission, and the New Mexico Engineer Office. We enjoyed the extremely close support from the different collaborating State agencies and are grateful for their assistance.

We hope the report will provide information of use to you and to the people of New Mexico in general.

Sincerely yours,

Stewart L. Udall,
Secretary of the Interior.

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INTRODUCTION

(By G. 0. Bachman, U.S. Geological Survey, Denver, Colo.)

This report summarizes the mineral and water resources of New Mexico. The use, manner of occurrence, distribution, and outlook for all known mineral commodities in the. State are discussed in separate chapters. Where available, statistics on the production of mineral commodities are summarized. In an introductory section the mineral industry and the geology of the Stale are outlined briefly.

The purpose of this report is to present an objective appraisal of the resources of New Mexico based on information now available, although new discoveries and changes in economic conditions may alter some of the conclusions reached. Treatment of each commodity is necessarily brief but comprehensive bibliographies are included for the convenience of those who may wish to inquire further into the mineral and water resources of New Mexico.

In this report the term "resources" applies to materials in the ground that are known to be minable; materials that may come into demand and become minable in the future; and water. "Reserves" are materials that may or may not be completely explored but may be quantitatively estimated and are considered to be economically exploitable at the time of the estimate. Reserves fluctuate because they are dependent on economic conditions, technologic factors, and available information. A low reserve figure does not necessarily mean that the resource is near exhaustion. It may indicate exploration is lacking or that a depressed market has lowered the value of the commodity to the point where the material can no longer be considered economically exploitable. "Ore" is mineral material that may be mined at a profit. "Protore." used in some parts of this report, is a mineral material that may not be mined at a profit under present economic or technologic conditions.

This report was compiled by members of the U.S. Geological Survey in cooperation with other Federal and State agencies. Members of the staff of the New Mexico Institute of Mining and Technology, State Bureau of Mines and Mineral Resources, contributed chapters to the report and cooperated in the search for data. Staff members of the New Mexico Oil Conservation Commission contributed discussions and statistics on the petroleum industry in the State. The New Mexico State Engineer Office cooperated in preparation of the section on water resources. Some chapters in this report have been prepared by personnel of the U.S. Bureau of Mines. Mr. George 0. Bachman, U.S. Geological Survey, assembled the various sections of the report. and coordinated efforts of the individual authors. Unless otherwise stated, statistical data used in the report have been compiled by Margaret Dunbar of the Bureau of Mines and Ruth Wilson of the Geological Survey under the direction of D. II. Mullen, U.S. Bureau of Mines, Mineral Resources Office (Statistics).

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MINERAL INDUSTRY IN NEW MEXICO

(By G. 0. Bachman, U.S. Geological Survey, Denver, Colo.)

In 1962 New Mexico ranked seventh among all the States in annual production of mineral resources and first among the States of the Rocky Mountain region. During this year New Mexico contributed 3.58 percent of the total domestic minerals produced in the country. The mineral resources that contributed chiefly to this wealth are petroleum, natural gas and related products, uranium, potassium salts, and copper. New Mexico ranks sixth among the Nation's oil- and gas-producing States, first in production of uranium and potassium salts, and third in the production of copper.

The total value of mineral resources produced in New Mexico for the 58year period 1905 through 1963, for which accurate, records are available, is $9,083.8 million. To this total may be added an estimate of $26.7 million in mineral production from the earliest mining to 1904 (Jones, 1904, p. 345) thus making in grand total of $9,110.5 million for all known mineral production in New Mexico through 1963. About 88 percent of this amount, or $8,158.7 million, has been produced since 1940. Figure 1 shows the annual dollar value' of mineral production from 1905 to 1963 and illustrates the growth of the industry in the State. Figure 2 shows the percentages of the principal mineral commodities produced in New Mexico in 1963 whose value totaled $686.8 million.

Geographically, the greatest mineral wealth produced in New Mexico during 1963 came from the San Juan Basin in the northwestern part of the State and the Delaware basin in the southeastern part. The combined value of crude petroleum, natural gas, uranium, and coal from the San Juan Basin, and crude petroleum, natural gas, and potash salts from the Delaware basin was about $599 million. The next most significant production figure was that of the southwestern part of the State where the production of copper and associated minerals was valued at about $59 million. The value of other mineral commodities produced throughout the State during 1963 was over $28 million.

The search for minerals of economic value in the area that is now New Mexico began more than 400 years ago. Rumors of mineral wealth resulted in the first major exploratory expedition in New Mexico in 1540. That expedition, under the command of Francisco Vasquez de Coronado, returned disappointed to Mexico in 1542; hut it was followed by other explorers, missionaries, adventurers, and finally by settlers in search of permanent homes.

Records of development of mineral resources during the colonial period from the late 16th to the early 19th centuries are meager. Twitchell (1916, vol. I, p. 1, 2) listed an archive pertaining to the registration of a mine "in the little mountain called Fray Cristobal"

I Dollar value is the amount in dollars reported for the year of production.

in 1685. Twitchell stated that this mine was "probably situated west of the present town of Engle, Sierra County, N. Mex." The mine was probably not worked as it was registered during the period of the Pueblo Revolt. Numerous registrations of other mines during the Colonial period are recorded. Vaguely worded registrations of

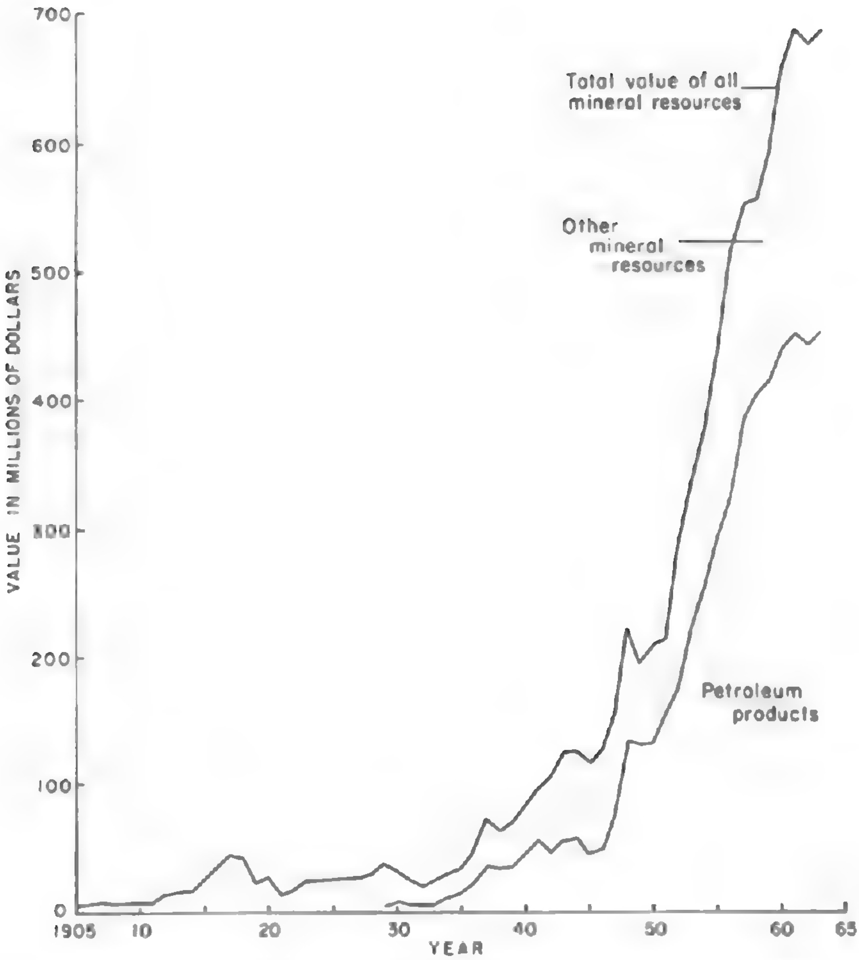


FIGURE 1.—Value of mineral resources produced in New Mexico, 1905–63.

mines as well as misinterpretations of some colonial reports have resulted in a colorful literature of rich, "lost" Spanish mines.

Some prospecting was reported done in the area that is now New Mexico in the 17th and 18th centuries, hut there is little evidence of extensive mining in New Mexico during Spanish colonial time. The Spanish word *mina,* as used in colonial reports and documents, may be translated as "mineral occurrences" and "prospects" as well as

"mines." Northrup (1959, p. 12) has pointed out that the more optimistic translation of the term mina to mean "mines" may have stimulated the search for these "mines" and thus may have been responsible for the discovery of valuable mineral deposits by later prospectors.

Some small-scale mining in Santa Fe County was carried out in the 17th century. Salt deposits in the Estancia Valley, Torrance County, were developed in the 17th and 18th centuries. This salt was

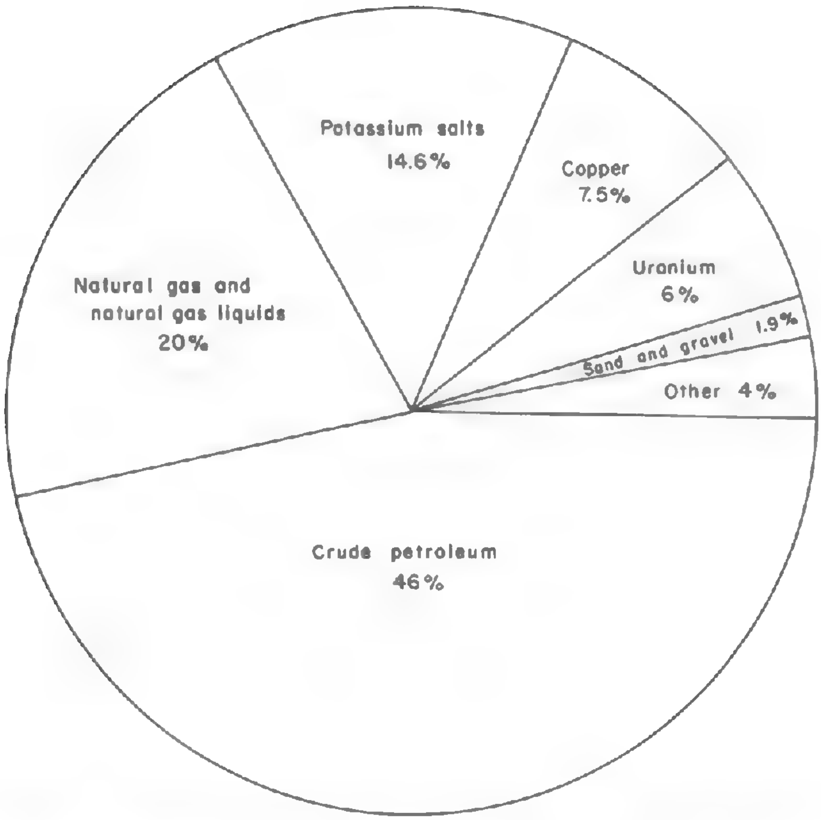


FIGURE 2.—Percentage of total mineral resource production in New Mexico, 1963.

carried by wagons and pack animals to the silver mines in Parral, Mexico, where it was used in the primitive "patio" metallurgical process for the extraction of silver from ore. Mica was used for window panes. The first major mine was opened in the area that is now New Mexico in about 1804 near the present Santa Rita mine, Grant County.

Extensive prospecting was conducted in the State in the late 19th century and it was during this period that most of the major min-

ing districts in New Mexico were discovered. Major deposits of uranium, however, were not discovered until after 1948 when the demand for uranium that developed during and after World War II was the incentive for prospecting for this metal.

Although the State was prospected extensively during the late 19th and early 20th centuries, new tools that are now available to the modern prospector have essentially reopened the field to further work that could lead to major new discoveries. The science of geophysics with its newly developed instruments for use in the air and on the ground has become much more sophisticated and highly specialized. Geochemical prospecting is a rapidly developing and practical field technique for the detection of small, but of anomalous amounts of metals in soil, water, and plants. Isotope chemistry and physics, X-ray and spectroscopic analysis, highly sensitive chemical techniques, and other refined laboratory methods make possible the more accurate identification and quantitative determination of trace amounts of elements that may give clues to the location of undiscovered ore deposits.

The future of mineral resources production is dependent on continuing demand, discovery, exploration, and development. As indicated in numerous chapters in this report, development of many of New Mexico's resources is increasing. With the increased use of coal in the production of electricity, the coal industry will probably continue to expand. On the other hand, the future of the uranium industry is less predictable at present. Uranium production will be regulated by government. purchases through 1970. Beyond 1970 the production of uranium will depend on industrial demand or continued government purchase. The growing demand for silver and other metals, along with new uses for many minerals by modern technology, indicates that exploration for these resources will increase.

Of all the natural resources of a state or a nation, none is probably more important than water, but also, none is more difficult to evaluate in terms of dollars and cents. It is significant to note that New Mexico occupies a unique and pioneering position in the use of its water resources. As stated by McGuinness (19G3, p. 558), New Mexico was among the earliest States "to be explored and settled, and hydrologically too it was among the pioneers. The U.S. Geological Survey learned how to measure streamflow at an experimental camp set up at Embudo, on the Rio Grande halfway between Santa Fe and the. Colorado line, late in 1888 after the Congress appropriated money for an irrigation survey of the arid lands and thus added water resources investigations to the Survey's responsibilities (Dutton, 1890, pp. 78-79). Some of the classical work of Slichter (1905 a, b) on estimation of ground water flow was done in the Rio Grande valley in New Mexico and Texas, in the vicinity of El Paso. The Survey's investigation, in cooperation with the State Engineer and Chaves and Eddy Counties, of the ground water resources of the Roswell artesian basin (Fiedler and Nye, 1933) was one of the pioneer quantitative ground water studies. It led directly to enactment of the New Mexico ground water law of 1927 and 1931, which was the earliest, of its kind and has served as a model for similar laws in several other States (National Resources Planning Board, 1943, pp. 76, 123, 133-134; Hutchins, 1955b, p. 47). The Rio Grande Joint Investigation * * * was the first interstate planning study of its type."

The study of the water resources of the State is a continuous process. Streamflow data are collected at 193 sites. Reservoirs are monitored at 16 sites. Daily chemical-quality records are maintained for 17 sites and daily suspended sediment samples are collected at 21 sites. In addition to this work, local and regional water resource studies are in progress.

TOPOGRAPHY AND GEOLOGY

(By C. H. Dane, U.S. Geological Survey, Washington, D.C., and G. 0. Bachman, U.S. Geological Survey, Denver, Colo.)

TOPOGRAPHY

New Mexico is the fifth largest State in the Union, including an area of 121,666 square miles of extraordinary diverse terrain, both topographically and geologically. The total topographic relief within the State boundaries is more than 10,000 feet. The highest point, 'Wheeler Peak, 30 miles south of the Colorado border in the Sangre de Cristo Mountains, reaches an altitude of 13,160 feet; the lowest point, Red Bluff Reservoir on the Pecos River along the southern boundary of the State, lies somewhat less than 3,000 feet above sea level. By far the largest part of the area of the State, however, lies at altitudes of between 5,000 and 10,000 feet above sea level. Between one-quarter and one-third lies below 5,000 feet, principally east of a diagonal line extending irregularly northeastward from the vicinity of Carlsbad to the Oklahoma boundary in the northeast corner. Other large areas below 5,000 feet include the valley of the Rio Grande from the southern boundary north to a short distance north of Albuquerque, the Jornada del Muerto and Tularosa Valley, and some thousands of square miles of similarly aggraded plains in the southwestern part of the State.

About 1,000 square miles of area rise above the 10,000-foot contour. This includes chiefly peaks in the Southern Rocky Mountains in the north-central part of the State, particularly in the Sangre de Cristo, Cimarron, San Juan, Jemez, and San Pedro Mountains. Smaller areas of more than 10,000 feet altitude occur on Mount Taylor, the Sandia and Manzano Mountains in the central part of the State, and on the Magdalena, San Mateo, Capitan, and Mogollon Mountains and the Black Range and Sierra Blanca in the southern part (fig. 3).

Topographically the State can be divided into three principal divisions, the Great Plains province of about the eastern one-third, the Intermontane Plateaus comprising most of the remainder, and the Southern Rocky Mountains including a relatively small portion of the north-central part (fig. 4). The boundaries between these divisions and between the subdivisions of those to be described are transitional and in places necessarily somewhat arbitrary. They do, however, represent distinctive terrains that are related to the bedrock geology and to the geologic history of the State.

The Great Plains Province includes: (a) the High Plains, extensive, smooth, high level, fluviatile plains, only slightly dissected in any area within the State, *(b)* the Pecos Valley, late mature to old plains, somewhat younger and at lower levels than the High Plains, and *(c)* the Raton Section, a considerably more varied area than the others, but in general a trenched or deeply eroded peneplain surmounted by dissected lava-capped plateaus and buttes. The Intermontane Plateaus of the western part of the State have been divided

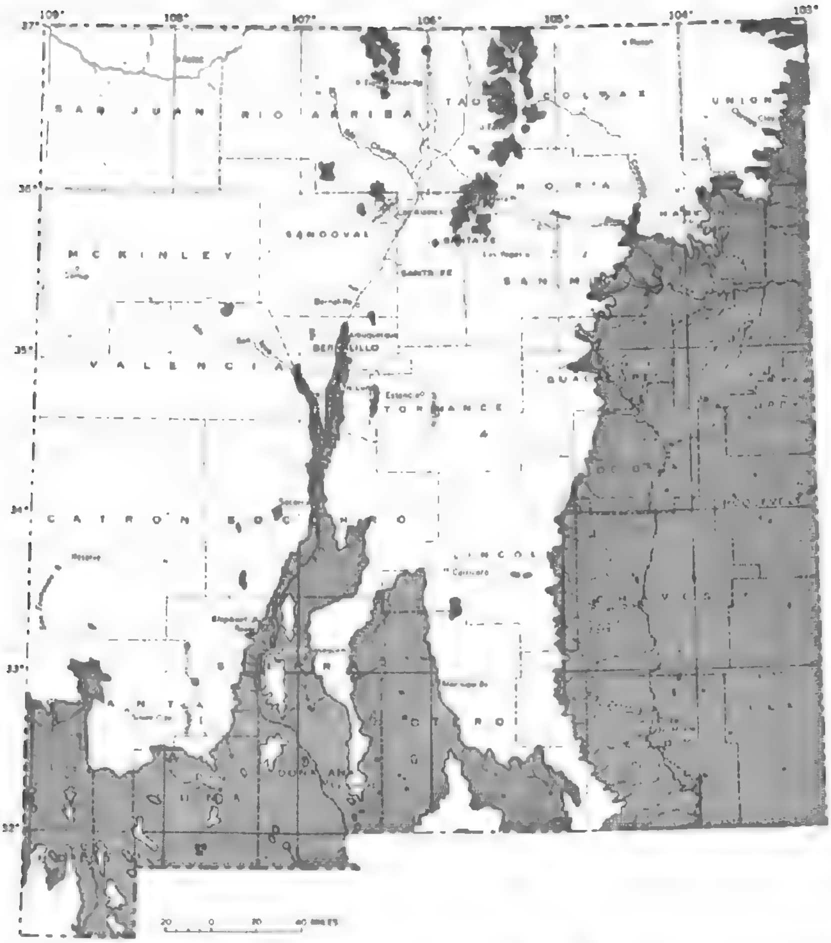


FIGURE 8.—Generalized relief map of New Mexico. Line pattern shows areas above 10,000 feet in altitude; gray, areas below 5,000 feet in altitude.

into two provinces, the Colorado Plateaus in the northwest and the Basin and Range Province in the southwest and central part of the State. The Colorado Plateaus include the Navajo section of the Canyon lands, chiefly young but canvoned plateaus of moderate relief and the Datil section to the south, including laval flows, complete or in extensive remnants, volcanic necks, and other extrusive and intrusive rock masses. The Basin and Range Province also includes two sections within New Mexico, the Mexican Highland, including isolated ranges (largely dissected block mountains) separated by aggraded desert plains and the Sacramento section, mature block mountains of gently tilted strata, block plateaus and bolsons.

The Southern Rocky Mountains Province includes only a relatively small part of the State along its northern border and is generally considered as terminating to the south at the southern end of the Sangre

de Cristo Range and the Nacimiento Mountains. Nevertheless, the generally meridional trend of these mountains is continued southward to the southern border by a succession of ranges of not greatly dissimilar geologic features. These ranges include the Sandia, Manzano, and Los Pinos Mountains; the Fra Cristobal and Caballo Mountains;

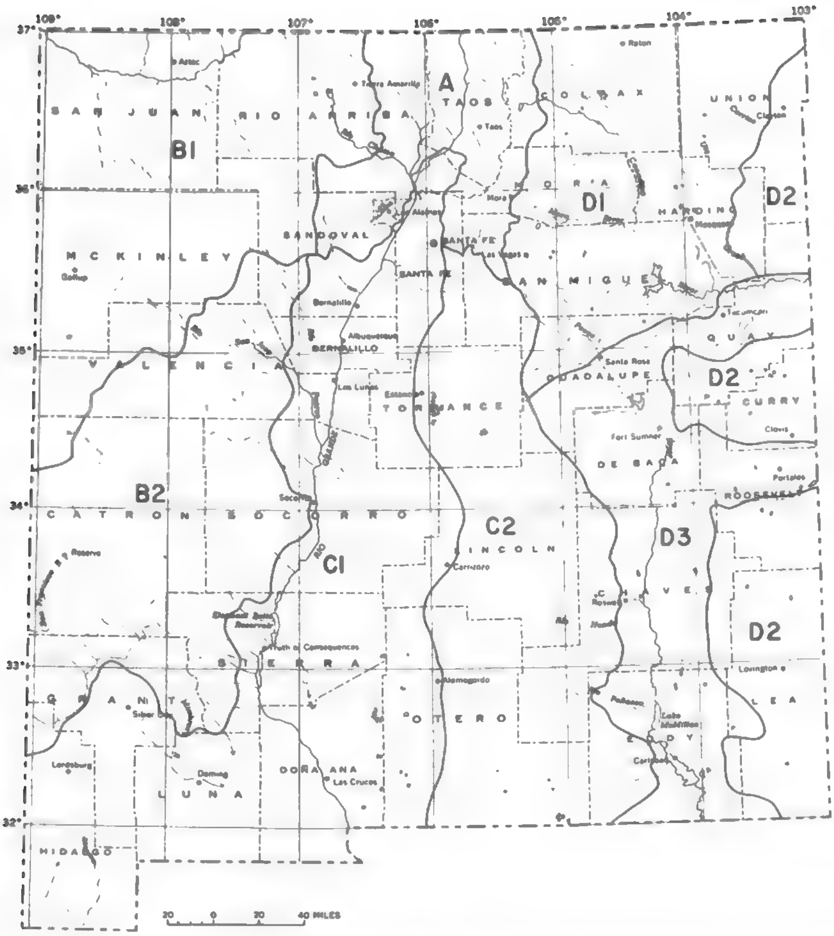


Figure 4.—Physical divisions of New Mexico. (A, Southern Rocky Mountains; B1, Colorado Plateaus, Navajo section; B2, Colorado Plateaus, Datil section; C1, Basin and Range province, Mexican highland; C2, Basin and Range province, Sacramento section; D1, Great Plains province, Raton section; D2, Great Plains province, High Plains; D3, Great Plains province, Pecos Valley. (Fenneman, 1962.)

the Oscura, San Andres, Organ, and Franklin Mountains; and Sierra Blanca and the Sacramento Mountains (fig. 5). These ranges, though separated by much wider deeply alluviated valleys, in the aggregate form a belt 50 to 100 miles wide from east to west that extends from the northern to the southern boundary of the State and in a broad

way divides the plateau, lava, and canyon lands in the western part of the State from the plains and areas of generally lower topographic relief of the eastern part.

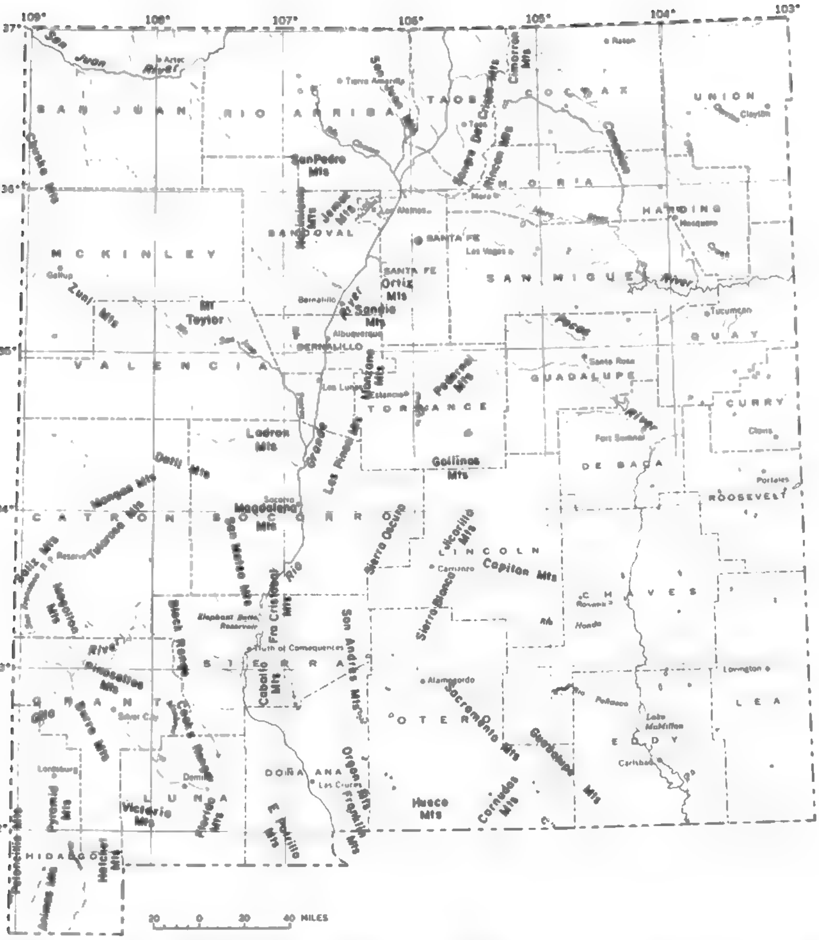
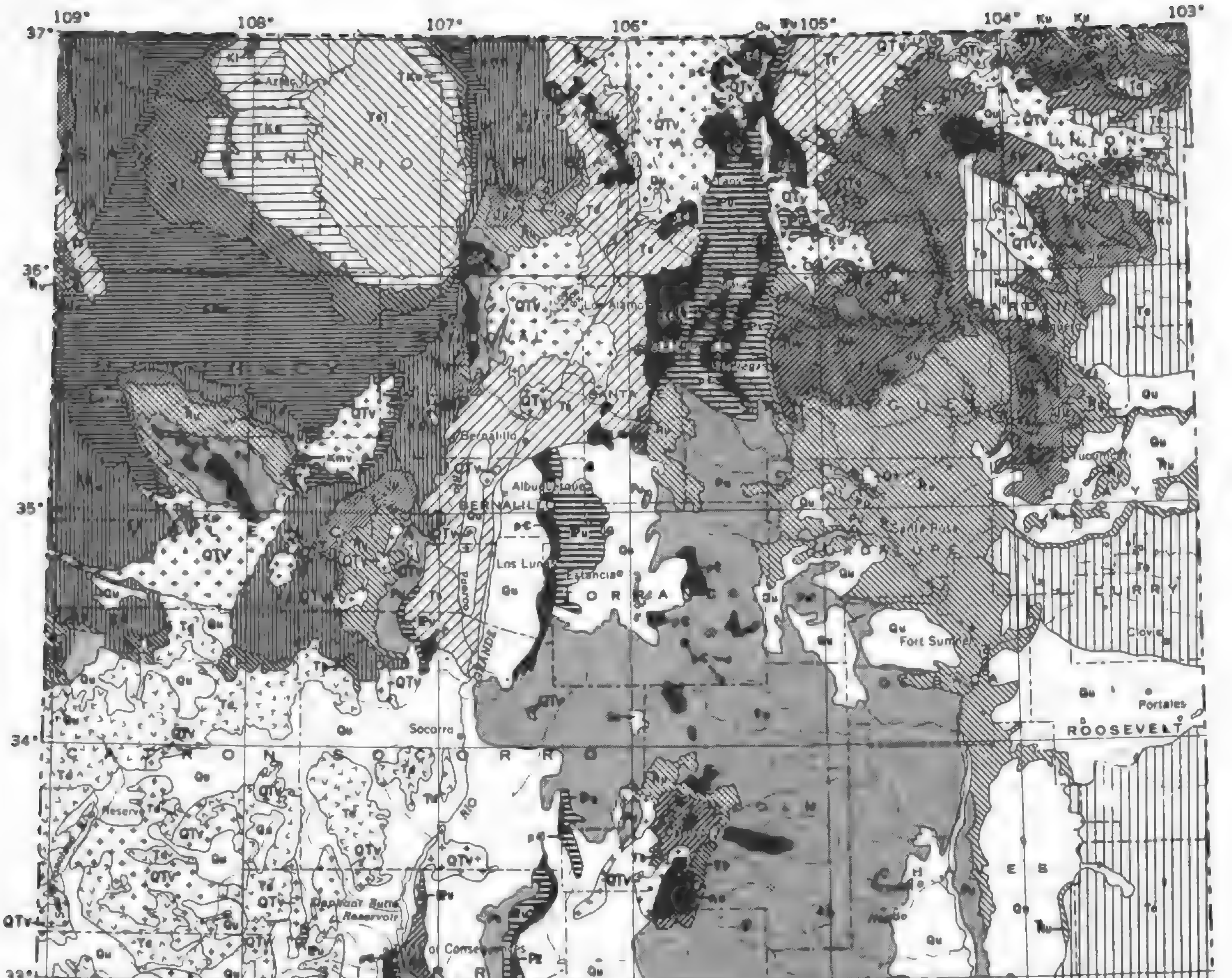


FIGURE 5.—Index map showing location of principal mountain ranges and rivers in New Mexico.

GEOLOGY

The rocks exposed in the ranges, mesas, and plateaus. and concealed beneath the alluviated plains and desert basins record a long and infinitely varied geologic history. At times nearly all the State was submerged beneath shallow seas. At other times much of the State stood above the level of the sea and the previously formed rocks were eroded and transported to other areas. During some ages great deserts of wind-blown sand swept across the State; and, at other times, areas marginal to extensive seas were vast evaporting pans in which thick deposits of gypsum or other salts crystallized from the concentrated



EXPLANATION

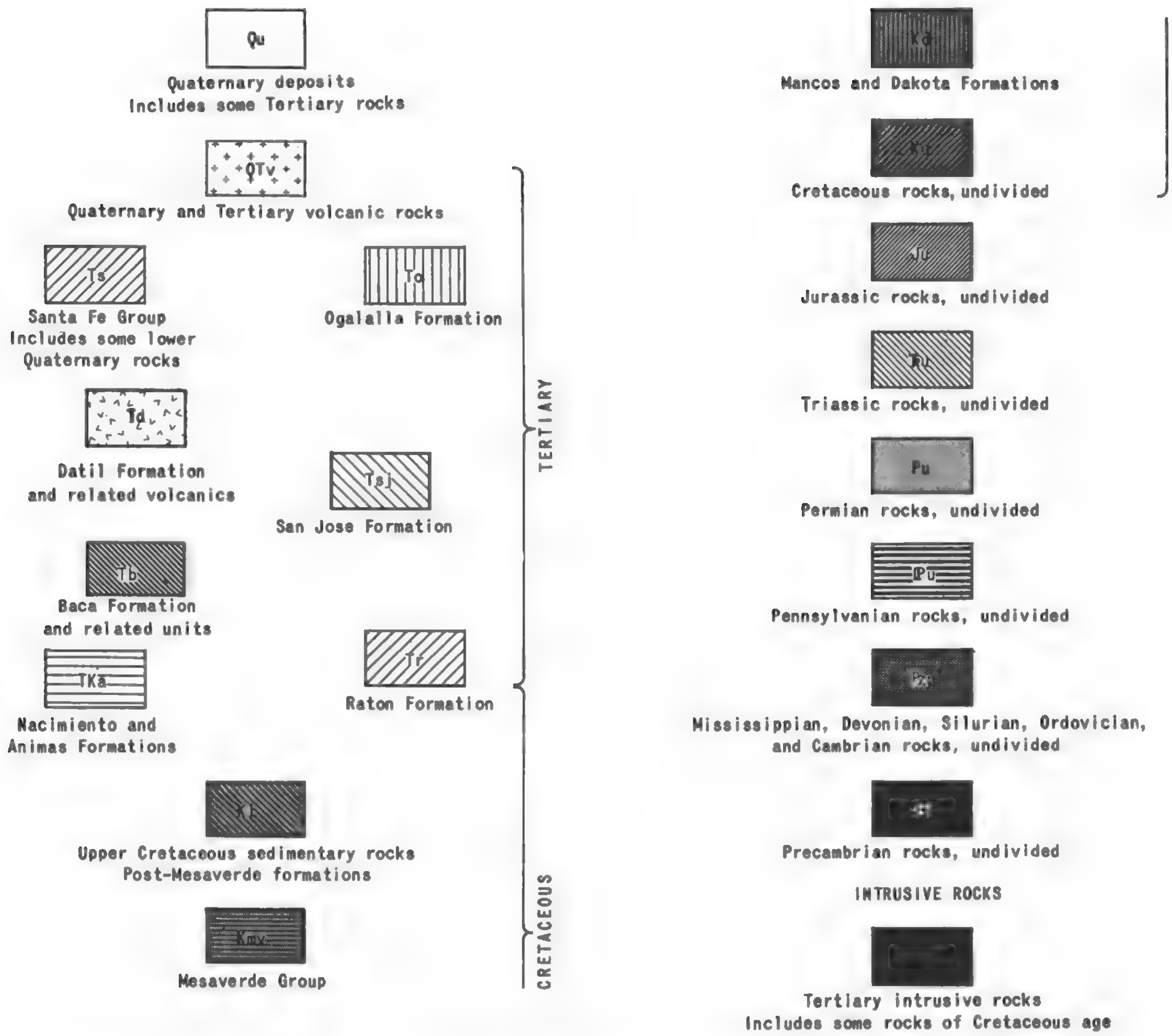


FIGURE 6.—Geologic map of New Mexico. (Generalized from geologic map of New Mexico by Carle H. Dane and George O. Bachman, U.S. Geological Survey, *in press*.)

brines. At still other times river and flood-plain deposits ranging from great boulders and coarse gravel, to fine sand, and to clay were strewn thickly over wide surfaces above the level of the sea, and extensive swamps bordering the seas accumulated thick beds of decaying plant detritus that subsequently were compressed and modified into coal. At times too, molten rock from the depths of the earth forced its way into the already consolidated sedimentary rocks, or burst through to the earth's surface as volcanos, which distributed windblown ash or emitted great sheets of lava. Many of these widely varied rocks contain mineral resources of economic value. The distribution and value of mineral resources are understood most adequately through a fuller understanding of the geologic processes that created them. The rocks that record the history of these processes are briefly described in the following pages. The generalized geologic map (fig. 6) shows the distribution of some of these rocks as they are exposed on the surface today.

Rocks of every geologic system into which strata have been classified in the United States crop out within New Mexico and are extensively distributed in the subsurface, where they have been encountered by the thousands of wells that have been drilled for oil or gas (tables 1-4). The rocks belonging to all but the oldest category are dominantly, though not exclusively, sedimentary rocks. That is, they were deposited as sediments by rivers, wind, or ocean currents and subsequently consolidated into bedded layers of rock. Much of this volume of sedimentary rock is distinguished by the presence, in greater or lesser amounts, of organisms of varied kinds, the fossil remains of past life, by means of which the containing rocks can be recognized, correlated from place to place, and placed in order of relative age by their superposition in orderly sequences.

PRECAMBRIAN ROCKS

The oldest rocks in New Mexico are classified simply as Precambrian. Fossils are not present in these rocks and they can be subdivided only on the basis of rock type or absolute age. In some areas these rocks have been studied in detail; but, as they have not been studied regionally over the State, only generalizations may be made about their age and relationships.

Precambrian rocks form the floor on which subsequent sequences of rocks were deposited. These foundation rocks are commonly referred to as "basement rocks" or simply as "the basement". Many of these very old rocks have been intensely deformed and altered. Some have been recrystallized into new combinations of minerals or metamorphosed in other ways. Precambrian rocks in New Mexico now consist of quartzite, schist, gneiss, granite, and many other rock types.

Precambrian rocks crop out only in a small fraction of the area of the State, most extensively in the higher parts of the Sangre de Cristo, Cimarron, San Juan, and Nacimiento Mountains in the north-central part, of the State. They also are present in considerable areas of the uplifted cores of meridional ranges that transect the State from south to north, and in many smaller areas, some only a few acres in extent, scattered throughout the southwestern part of the State. Precambrian rocks do not crop out east of a diagonal line extending northeastward

TABLE 1.—*Nomenclature of principal formations in northwestern New Mexico*

Era	Geologic time units		Formations	
Cenozoic (to 70 million years)	Quaternary	Recent	Alluvium	
		Pleistocene	Gravel, sand, clay and volcanic deposits	
	Tertiary	Pliocene	Santa Fe Group	Chuska Sandstone
		Miocene		
		Oligocene	May be present (?)	
		Eocene	Galisteo Formation (Eocene and questionably Oligocene); Baca Formation (questionably Eocene); San Jose Formation	
		Paleocene	Nacimiento Formation; Animas Formation (Upper Cretaceous and Paleocene)	
Mesozoic (70-225 million years ±)	Cretaceous		Ojo Alamo Sandstone McDermott Formation Kirtland Shale and Fruitland Formation Pictured Cliffs Sandstone Lewis Shale	
			Cliff House Sandstone Menefee Formation Point Lookout Sandstone Crevasse Canyon Formation Gallup Sandstone	All of the Mesaverde Group
			Mancos Shale Dakota Sandstone	
	Jurassic		Morrison Formation Bluff Sandstone Summerville Formation Todilto Formation Entrada Sandstone (San Rafael Group)	Zuni Sandstone
	Triassic		Glen Canyon Group Wingate Sandstone Chinle Formation	
Paleozoic (225 to 600 million years ±)	Permian		San Andres Limestone Glorieta Sandstone	
			Yeso Formation Abo Formation	Cutler Formation Rico Formation
	Carboniferous	Pennsylvanian	Madera Formation Sandia Formation	Hermosa Formation Paradox Member Molas Formation
		Mississippian	Arroyo Penasco Formation	Present in subsurface (includes the Leadville Limestone)
	Devonian		Present in subsurface	Ouray Limestone Includes the Elbert Formation
	Silurian		Absent	
	Ordovician		Absent	
	Cambrian		Present in subsurface	Includes the Ignacio Quartzite
Precambrian (3 billion years ±.)			Granite, quartzite, pegmatites, etc.	

TABLE 2.—*Nomenclature of principal formations in northeastern New Mexico*

Era	Period	Geologic time units	Formations
Cenozoic (to 70 million years)	Quaternary	Recent	Alluvium, other surficial deposits, and some volcanic deposits
		Pleistocene	Gravel, sand, caliche and some volcanic deposits
	Tertiary	Pliocene	Santa Fe Group; Ogallala Formation
		Miocene	Santa Fe Group
		Oligocene (?)	Galisteo Formation and other local formations
		Eocene	
		Paleocene	Poison Canyon Formation Raton Formation
Mesozoic (70-225 million years /)	Cretaceous		Vermejo Formation Trinidad Sandstone Pierre Shale Niobrara Formation Carlile Shale Greenhorn Limestone Graneros Shale Dakota Sandstone Purgatoire Formation
	Jurassic		Morrison Formation Summerville Formation Todilto Limestone Entrada Sandstone
	Triassic		Dockum Group Chinle Formation Santa Rosa Sandstone
(225 to 600 million years /)	Permian		Artesia Formation San Andres Limestone Glorieta Sandstone Yeso Formation
	Permian and Pennsylvanian		Sangre de Cristo
	Carboniferous	Pennsylvanian	Madera Limestone Sandia Formation
		Mississippian	Tererro Formation
	Devonian		Espiritu Santo Formation
	Silurian		Absent
	Ordovician		Absent
	Cambrian		Absent
Precambrian (3 billion years /).			Granite, diorite, other plutonic rocks, schist, quartzite, and pegmatites.

TABLE 3.—*Nomenclature of principal formations in southwestern New Mexico*

<table>
<tr><th colspan="3">Geologic time units</th><th colspan="3">Formations</th></tr>
<tr><td rowspan="8">Cenozoic (to 70 million years)</td><td rowspan="3">Quaternary</td><td>Recent</td><td colspan="3">Alluvium, other surficial deposits and volcanic rocks</td></tr>
<tr><td rowspan="2">Pleistocene</td><td colspan="3">Gravel and volcanic rocks</td></tr>
<tr><td rowspan="3">Santa Fe Group</td><td>Gila Conglomerate</td><td rowspan="3">Datil Formation and associated volcanic rocks</td></tr>
<tr><td rowspan="5">Tertiary</td><td>Pliocene</td><td rowspan="2"></td></tr>
<tr><td>Miocene</td></tr>
<tr><td>Oligocene</td><td colspan="3">May be present (?)</td></tr>
<tr><td>Eocene</td><td colspan="3">Baca Formation of questionable Eocene age</td></tr>
<tr><td>Paleocene</td><td colspan="3">Not recognized (?)</td></tr>
<tr><td rowspan="5">Mesozoic (70-225 million years_/)</td><td colspan="2" rowspan="3">Cretaceous</td><td>Mesaverde Group</td><td colspan="2">Includes some volcanic rocks</td></tr>
<tr><td>Mancos Shale
Dakota Sandstone</td><td colspan="2">Colorado Shale
Sarten Sandstone & Beartooth Quartzite</td></tr>
<tr><td colspan="3">Bisbee Group:
Includes a sequence of conglomerate, sandstone, volcanic rocks, etc. more than 10,000 feet thick in extreme southwestern New Mexico.</td></tr>
<tr><td colspan="2">Jurassic</td><td colspan="3">Absent</td></tr>
<tr><td colspan="2">Triassic</td><td colspan="3">Present in northern part of region</td></tr>
<tr><td rowspan="8">Paleozoic (225 to 600 million years_/)</td><td colspan="2">Permian</td><td>Concha Formation
Scherrer Formation
Colina Limestone
Earp Formation</td><td colspan="2">San Andres Limestone
Glorieta Sandstone
Yeso Formation
Abo Formation
Bursum Formation</td></tr>
<tr><td rowspan="2">Carboniferous</td><td>Pennsylvanian</td><td colspan="3">Horquilla Formation -- Magdalena Group</td></tr>
<tr><td>Mississippian</td><td>Lake Valley Limestone
Kelly Limestone</td><td colspan="2">Escabrosa Limestone</td></tr>
<tr><td colspan="2">Devonian</td><td colspan="3">Percha Shale (and other local formations)</td></tr>
<tr><td colspan="2">Silurian</td><td colspan="3">Fusselman Dolomite</td></tr>
<tr><td colspan="2">Ordovician</td><td colspan="3">Montoya Dolomite
El Paso Formation</td></tr>
<tr><td colspan="2">Ordovician and Cambrian</td><td colspan="3">Bliss Sandstone</td></tr>
</table>

Precambrian (3 billion years_/). Granite and associated rocks.

TABLE 4.—Nomenclature of principal formations in southeastern New Mexico.

Geologic time units			Formations	
Cenozoic (to 70 million years)	Quaternary	Recent	Alluvium and other surficial deposits	
		Pleistocene	Gravel and associated deposits	
	Tertiary	Pliocene	Ogallala Formation	
		Miocene	Probably present (?)	
		Oligocene	Not recognized	
		Eocene	Not recognized (?)	
		Paleocene	Not recognized (?)	
Mesozoic (70–225 million years)	Cretaceous		Mesaverde Group Mancos Shale Dakota Sandstone (?)	
	Jurassic		Absent	
	Triassic		Dockum Group	
Paleozoic (225 to 600 million years /)	Permian		Dewey Lake Redbeds Rustler Formation Salado Formation Castile Formation	
			All of the Artesia Group	Tansill Formation Yates Formation Seven Rivers Formation Queen Formation Grayburg Formation
			San Andres Limestone includes the Hondo Sandstone Member Glorieta Sandstone Yeso Formation Abo Formation Bursum Formation	Cutoff Shale Victorio Peak Limestone Bone Spring Limestone Hueco Limestone
	Carboniferous	Pennsylvanian	Includes many formations and informally named zones in the subsurface	
		Mississippian	Lake Valley Limestone and other local formations	"Mississippian Lime" of subsurface
	Devonian		Percha Shale	Woodford Shale of subsurface
	Silurian		Fusselman Dolomite	"Devonian" of subsurface
	Ordovician		Montoya Dolomite	
			Simpson Formation of subsurface	
			El Paso Formation	Ellenburger Formation of subsurface
	Ordovician and Cambrian		Bliss Sandstone	
Precambrian (3 billion years /).			Granite and associated rocks.	

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from El Paso, Tex., to Raton, nor in the San Juan Basin in the northwestern part, nor in the central part of the Datil volcanic area of the southwest part of the State.

The exposed Precambrian rocks do not show a distinctive general pattern of distribution. Somewhat more of a pattern is displayed by the distribution of these rocks where encountered in drilled wells. Although more than 500 wells have reached Precambrian rocks, more than 200 of these are in eastern Lea County. The distribution of the remainder is sparse in many parts of the State. Nevertheless, these wells show that granite underlies much of the northeastern part of the State, the southeastern part of the San Juan Basin, most of the south-central and southwestern parts of the State, and large areas in Lea and Eddy Counties in the southeastern part.

Although the relative ages of the Precambrian rocks of the State are not well understood, it appears that the most deeply metamorphosed rocks are the oldest (about 1,110 to 1,300 million years) and that they are followed in age successively by intrusive granite and granitoid rocks, by relatively unmetamorphosed sedimentary rocks associated with intrusive and extrusive rhyolites, and by a younger group of granitic intrusive rocks. The increased amount of radiometric dating of the Precambrian rocks that will become available in the future will greatly clarify our understanding of the correlations and history of these rocks.

PALEOZOIC ROCKS

The Paleozoic Era is represented in New Mexico by a succession of sedimentary rocks which is divided into systems and local formations (tables 1-4). The older Paleozoic rocks are divided into Cambrian, Ordovician, and Silurian Systems. Rocks of these ages consist mainly of limestone and dolomite, and include some sandstone. They were deposited in shallow seas that oscillated across the land. Deposition was discontinuous and environments of deposition were variable. These factors have resulted in distinctive rock types in each system and the rock types may be divided into mappable formations.

During Late Cambrian and Early Ordovician time the Bliss Sandstone and El Paso Limestone were deposited in a sea that probably transgressed across the land from the west. Rocks correlated with the Middle Ordovician Simpson Group of Oklahoma are present in the subsurface in southeastern New Mexico and in Middle and Late Ordovician time the Montoya Dolomite was deposited in a continuous seaway across southern New Mexico. In Silurian time the Fusselman Dolomite was deposited in a sea that may have encroached on the land from the east. The seas were probably relatively warm and, during parts of early Paleozoic time, were hosts to many species of primitive corals, bivalves, crinoids, and other forms of animal life.

Rocks of the early part of the Paleozoic Era are preserved only in the southern and northwestern parts of New Mexico. Although these rocks may be as much as 2,500 feet thick in the south-central part of the State, they are eroded and generally absent north of the latitude of the Caballo and Fra Cristobal Mountains in Socorro County, and north of the Oscura Mountains in Lincoln County. They are well exposed in the Sacramento Mountains, Otero County, but are absent north of Alamagordo. They have been encountered in wells drilled

in the Delaware basin in southeastern New Mexico. The Ignacio Quartzite of Late Cambrian age has been encountered in wells in the northwestern part of New Mexico.

Younger Paleozoic rocks are included in the Devonian, Mississippian, Pennsylvanian, and Permian Systems. Rocks of these ages include limestone, dolomite, gypsum and anhydrite, salt, potash minerals, shale, sandstone, and conglomerate. They reflect changing environments of deposition.

The Devonian rocks, largely represented by the Percha Shale in southern New Mexico are relatively thin but form a widespread blanket of dark, calcareous to sandy shale. Devonian rocks have much the same distribution in New Mexico as the earlier Paleozoic rocks, but they are probably also present at places in the Sangre de Cristo Mountains.

Mississippian rocks consist mainly of limestone and are present over much of southern New Mexico as well as places in the Sangre de Cristo, Nacimiento, and Sandia Mountains. They are also present in the subsurface in northwestern part of the State. The Mississippian rocks, which have a maximum thickness exceeding 1,200 feet in southwestern New Mexico, have been assigned to a large number of locally recognized stratigraphic units.

Pennsylvanian and Permian rocks were deposited in widely variable environments including the flanks of mountains that rose out of the sea, shallow seas, enclosed basins, and salt pans. The rocks, therefore, are of great variety and have been assigned to numerous stratigraphic units. Pennsylvanian rocks include gypsum, limestone, sandstone, and conglomerate. Permian formations include those rock types as well as much dolomite and, in southeastern New Mexico, thick salt and potash deposits. In parts of southeastern New Mexico Pennsylvanian and Permian rocks may exceed 12,000 feet in thickness.

All the Paleozoic rocks are presently being studied intensively by geologists, for it is from these rocks that much of the petroleum is being produced in New Mexico. An understanding of regional variations in rock types, position of ancient shore lines and mountain uplifts, and environments of deposition are necessary to predict the occurrence of petroleum. In addition, the understanding of ancient uplifts and fracturing of rocks is important in the study of ore deposits. Because of this intensive study, numerous formation names have been proposed for rocks in New Mexico. These names are not listed here because of the complexity of nomenclature. The accompanying tables (tables 1-4) are intended to serve only as generalized outlines for reference.

MESOZOIC ROCKS

Deposits of Mesozoic age include rocks of the Triassic, Jurassic, and Cretaceous Systems. At the close of Paleozoic time seas withdrew from New Mexico and lower Mesozoic rocks are of continental origin. Triassic rocks in New Mexico are usually red to maroon and include shale and sandstone deposited on floodplains or in other subaerial environments. Triassic rocks are preserved in northern and eastern New Mexico. They are exposed in southeastern New Mexico along the Pecos River nearly to the State line. The maximum

thickness of Triassic rocks may exceed 2,000 feet along the eastern edge of the State.

Jurassic rocks include a complex sequence of nonmarine units, largely elastic, of eolian, stream, and lacustrine origin. They are exposed widely in northern New Mexico around the edges of the San Juan Basin where they locally exceed 1,000 feet in thickness, in mountain uplifts, and in deeply cut canyons including those of the Canadian and Cimarron Rivers. Jurassic rocks are not present in New Mexico south of an easterly line across the south-central part of the State.

During Cretaceous time seas again advanced over New Mexico and rocks were deposited in, or marginal to, a marine environment. The main body of the Cretaceous sea lay to the east of New Mexico and extended from the Arotic to the Gulf of Mexico. In southwestern New Mexico, however, the lowest Cretaceous rocks accumulated to thicknesses of more than 15,000 feet in a deep trough centered in the area of the Little Hatchet Mountains. Upper Cretaceous rocks were deposited over northern New Mexico in lagoons, along beaches, and in offshore and marine environments. Complex intertonguing relations record the oscillatory advance of the sea and differences in the rate of supply of sediment. The rocks consist of shale and sandstone with some beds of limestone and local coal beds.

The oldest formation in the Upper Cretaceous sequence is the widespread Dakota Sandstone. Overlying the Dakota in northwestern New Mexico is the Mancos Shale which was deposited as a marine mud. The Mesaverde Group consists of several formations that interfinger with the underlying Mancos Shale and record deposition of sand, silt, clay, and plant debris in streams and swamps. Almost the entire history of Upper Cretaceous deposition over much of New Mexico is marked by repeated advances of the sea with the drowning of rivers and swamps followed by retreat of seas and renewal of river systems and swamp environments. The well preserved record of these events in New Mexico has long intrigued geologists and the study of these rocks and their history has resulted in classic concepts of sedimentation, facies changes, and interfingering of strata.

CENOZOIC ROCKS

At the close of Cretaceous time, seas withdrew from the New Mexico region ; and regional uplift of the land, accompanied by mountain building, began. Therefore, there are no known marine deposits in New Mexico that are younger than Cretaceous age. Tertiary rocks consist of clay, shale, sandstone, volcanic flows, and igneous intrusions. Some coal beds were deposited in the Raton Basin during early Tertiary time.

During the earliest part of Tertiary time, sediments were deposited in the San Juan and in the Raton Basins. The Tertiary rocks in the San Juan Basin include gray shale, variegated red, purple, and white shale, sandstone, and brown conglomerate. Rocks in the San Juan Basin were probably deposited on the surface of floodplains that contained some areas of a heavily wooded savanna environment. In the Raton basin lower Tertiary rocks consist of coal, gray shale, and interbedded conglomerate sandstone beds that interfinger and grade into the

overlying conglomerates. These rocks were deposited in a swamp and floodplain environment that was covered later by a piedmont terrane.

Other sedimentary formations were deposited in intermontane basins in Tertiary and early Quarternary time. These include the Galisteo Formation of Eocene and Oligocene (?) age in southern Santa Fe County, the Baca Formation of Eocene (?) age in central New Mexico, and the Santa Fe Group of Miocene to Pleistocene (?) age in the vicinity of the Rio Grande Valley. The Santa Fe Group consists of clay, sand, gravel, and some interbedded volcanic rocks. The Santa Fe Group is best exposed in northern Santa Fe County but it may be present along much of the course of the Rio Grande in New Mexico. The Pliocene and Pleistocene Gila Conglomerate in southwestern New Mexico is very similar lithologically to the Santa Fe Group.

In southwestern New Mexico there was extensive volcanic activity and local igneous intrusions during Tertiary time. The Datil Formation, chiefly of Tertiary age, formed a volcanic field that covers much of Catron, Grant, and western Socorro and Sierra Counties. Some volcanic rocks in Hidalgo, Luna, and Dona Ana Counties may be related to the Datil volcanic episode.

Rocks of Quaternary age in New Mexico include sedimentary and igneous deposits. The sedimentary deposits include caliche, alluvium and valley fill, clay, sand, and gravel. The igneous rocks include volcanic flows and ash falls of varied composition.

The sedimentary rocks are chiefly the result of weathering and breakdown of mountain masses. Products of weathering have been carried by streams into valleys where they are deposited. Most Quaternary sedimentary deposits are unconsolidated and friable but in some areas chemical processes in nature are operative and well-cemented spring deposits (travertine) are in the process of formation. In some enclosed basins, as in the Estancia Basin in eastern Valencia County and the Tularosa Basin in western Otero County, saline deposits have accumulated during relatively recent time. These deposits are the result of saline-bearing water that evaporates into the atmosphere leaving saline crystals as deposits on or near the surface of the ground. Dunes of the White Sands in Otero County are composed of small grains of gypsum that have been fragmented in the atmosphere and moved and rounded by wind action.

During Pleistocene time, commonly known as the "Ice Age," glaciers were not as widespread in New Mexico as in the northern part of the United States. Mountain glaciers formed in parts of the Sangre de Cristo Mountains and as far south as Sierra Blanca Peak in Lincoln County, but ice did not cover New Mexico in sheets. During the time of glaciation the climate in New Mexico was probably much wetter and colder than present climate. About 12,000 to 13,000 years ago man was hunting the mammoth and other large animals in the area, that is now New Mexico. Average summer temperature in the Estancia Valley in Torrance County was 10° to 12° lower than at present and the annual precipitation was probably 8 inches more than present precipitation. During the past 6,000 years, climate has been variable with a tendency towards relatively warm and more arid conditions. The variable climate of recent time is reflected by several cycles of arroyo cutting and filling in the drainage systems of New Mexico.

GEOLOGIC STRUCTURE

Deformation of the earth's crust is a long and continuing evolutionary process that results in the development of land forms and changing geologic environments. Mountains and basins present today in New Mexico reflect a relatively late episode in the structural history of the region (fig. 7). Some modern geologic structures may, however, be related to structural weakness in the earth's crust that first developed in Paleozoic, or Precambrian time, but continuing folding, faulting, and crumpling of rocks has masked much of the earlier structural history.

The relatively small exposures of Precambrian rocks limit the regional interpretation of the origin and history of these rocks. Seaways were present and sediments were deposited. Later these sediments were lithified, subjected to regional stresses, and intruded by igneous rocks. The lithified and metamorphosed sediments are preserved in the form of schist, quartzite, and gneiss. In the Sandia and Manzano uplifts, east and southeast of Albuquerque, and in parts of southeastern New Mexico there was some volcanic activity during Precambrian time.

During much of Paleozoic time the relief in New Mexico was low and intermittent encroachment of seas over the area was characteristic. Structural movements were probably confined to low regional warping of the earth's crust. During late Paleozoic (Pennsylvanian and Early Permian) time there was local mountain building and land masses were lifted above the surrounding sea. This uplift, and accompanying erosion of rocks, may account in part for the absence of lower Paleozoic rocks over much of north-central New Mexico. At this time the Sierra Grande arch, Pedernal arch, Matador arch, Central Basin platform, and the Zuni uplift were formed. These uplifts, sometimes called the Ancestral Rocky Mountains, contributed sediments to adjoining basins during Pennsylvanian and earliest Permian time. A remnant of the Pedernal arch forms the present Pedernal Hills in Torrance County. The Zuni uplift was rejuvenated during Tertiary time and is a prominent landmark in western New Mexico today. Other uplifts that were in existence in Early Permian time are now covered by strata deposited in Permian and later time. The cores of those uplifts have been found during drilling for petroleum.

During Mesozoic time tectonism was relatively mild in the New Mexico region. In Jurassic time the eastward trending Navajo highland—an area of low relief and nondeposition—existed in central New Mexico. Owing to the presence of this highland, strata of Jurassic age are not found, and may never have been deposited, in the southern half of the State. During Cretaceous time gentle crustal warping resulted in encroachment of seaways and the oscillation of shorelines in the northwestern part of New Mexico, and possibly elsewhere. At this time highlands were present in western Arizona and, during Late Cretaceous time, in southwestern New Mexico. Volcanoes may have been active in southwestern New Mexico.

Regional uplift accompanied by folding and local thrust faulting was the dominant tectonic activity in latest Cretaceous and earliest Tertiary time. Regional tectonic forces were probably compressional as contrasted with tensional stress of later Tertiary time. At least

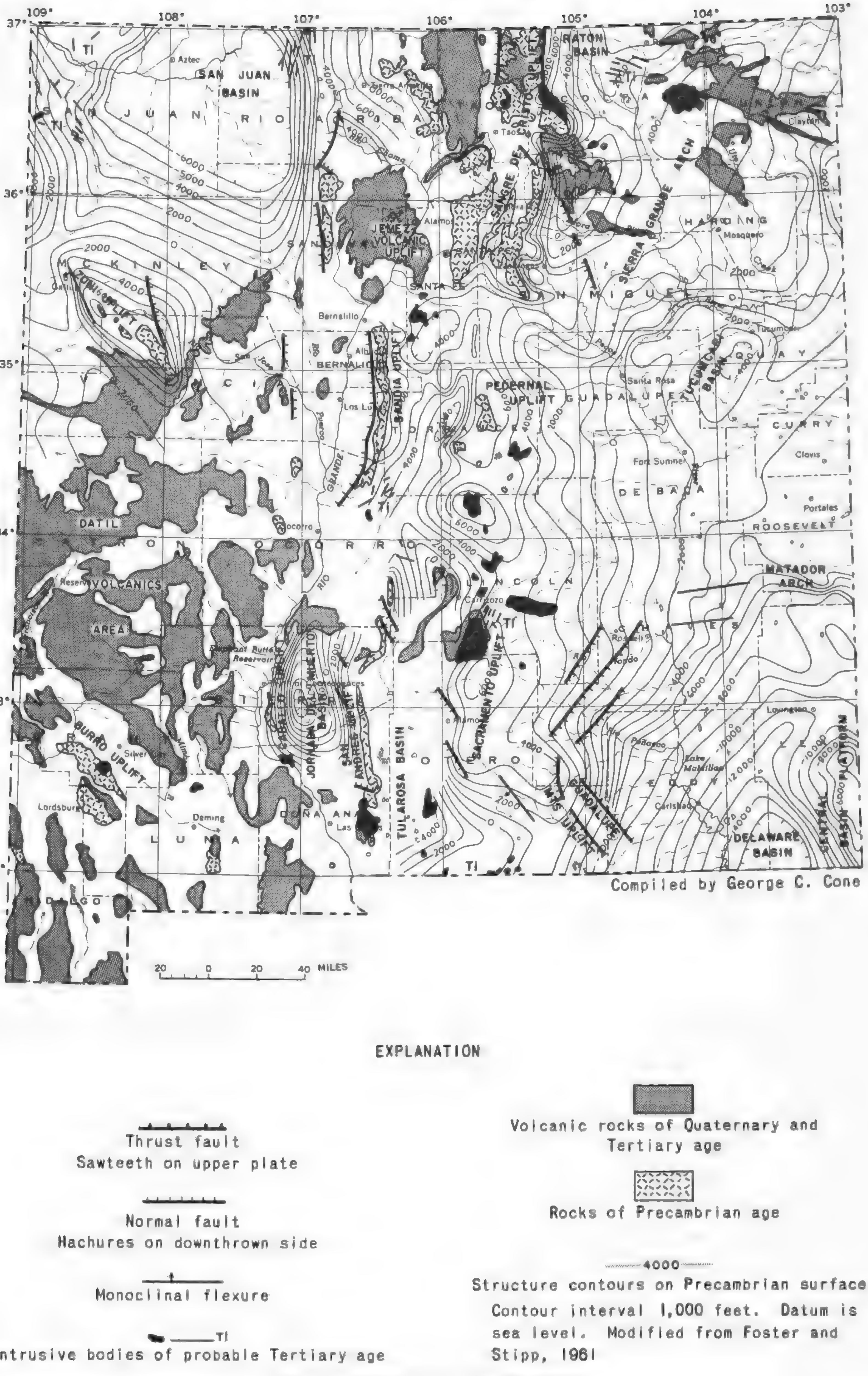

FIGURE 7.—Generalized tectonic map of New Mexico.

as early as Oligocene time tensional stress resulted in normal faults and widespread volcanic activity. The Datil volcanic field, Mount Taylor, and local igneous intrusions were developed at this time. During late Tertiary time most of the mountains and basins that are part of the present landscape of New Mexico were formed.

Late Tertiary igneous activity has produced relatively high and well-known landmarks. Intrusion of igneous rock from magmas into the earth's crust formed the Organ Mountains near Las Cruces, parts of Sierra Blanca in southern Lincoln County, and the Ortiz Mountains in Santa Fe County. Explosive volcanism formed parts of the Jemez volcanic plateau and less violent volcanic activity resulted in the building of Mount Taylor in McKinley and Valencia Counties.

An understanding of the sequence of structural events is significant to the location of mineral resources. Magmatic differentiation of igneous rocks during igneous intrusion results in the formation of pegmatites and other concentrations of minerals. Contact metamorphic deposits are formed along the margins of igneous intrusions. The movement of mineral-bearing solutions and gases in faults and fissures results in the concentration of minerals. Tilting of strata results in the movement of mineralizing flu; ds, water, and petroleum, in the rocks. The relative position of shorelines to sea and land are at times the key to the location of coal and petroleum resources.

ECONOMIC GEOLOGY

The economic value of a mineral resource is determined by the cost of production, cost of transportation to market, and by the demand for the commodity. Costs and demand vary with fluctuations in local or national economy, advances in the technological fields of exploration and exploitation, and increases in requirements by industry and the expanding population. A resource that cannot be developed profitably today may become the basis for a profitable enterprise in the future because of these constantly changing sociologic, technologic, and economic factors.

Once a mineral resource is exhausted it cannot be replaced. This fact of depletion is a distinctive characteristic of mineral economics and creates problems both in concepts of conservation and execution of resource development. For this reason, efficient development, intelligent use, and continuing search for new or substitute mineral resources are of importance to economic growth. Advances in the techniques of exploration and processing of mineral resources have been successful in meeting the most fundamental needs of the nation's economy to date. However, with depletion of high-grade deposits it will become necessary to locate and develop deposits that are of lower grade, particularly those that give promise of yielding more than one mineral commodity, others that are deeply buried, and still others that are farther from markets.

The accumulation of a mineral or rock to form an economic deposit is the result of one or more specific geologic processes, and therefore each type of mineral resource is limited in distribution to certain geologic environments. In fact, environments conducive to the formation of mineral deposits are so restricted in nature that it has been estimated that during the past 50 years, 90 percent of the Nation's gold,

silver, copper, lead, and zinc has come from a total area of less than 1,000 square miles (Fowler and others, 1955, p. 7) .

The geologic occurrence of all mineral deposits follows natural laws that allow basic predictions. Mineral fuels, such as petroleum, natural gas, and coal, are natural products of organic decay and recomposition in a sedimentary environment, and these resources are found in sedimentary rocks. In New Mexico these rocks are best preserved in the thick sedimentary deposits in the San Juan and Delaware basins. Petroleum and natural gas are found in these basins in rocks of Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, Permian, and Cretaceous ages.

Extensive deposits of coal occur in New Mexico in rocks of Cretaceous age in the San Juan Basin, and of Cretaceous and Paleocene ages in the Raton Basin. Rocks of Cretaceous age also contain coal deposits in the Carthage, Sierra Blanca, Hagen (Una del Gato), and Tijeras basins.

Other minerals are concentrated in deposits by solutions or gases emanating from deep-seated bodies of magma. These deposits are usually found in association with igneous and metamorphic rocks and occur within, or adjacent to, mountain uplifts. Some occur as veins along fractures, some as bodies that have replaced favorable rocks, and some as disseminated mineral grains in large masses of igneous rock.

Veins occur in New Mexico in the Lordsburg, Silver City, Mogollon, Lake Valley, and Magdalena districts. They have produced gold, silver, copper, and nonmetallic minerals. Replacement bodies of ore occur in wall rocks near veins or in the vicinity of igneous intrusions. Such deposits have produced lead in the Kingston, Hillsboro, Lake Valley, and other districts in New Mexico. Disseminated copper deposits are mined in the Silver City region.

Some minerals of economic importance are concentrated by processes of weathering and erosion of uplifted areas, and occur as products of deposition. These deposits include vast accumulations of sand and gravel in New Mexico, placer gold, and some clay deposits. Other deposits are enriched by weathering and oxidation.

Some rocks are of direct economic value. These include potash, salt, gypsum, perlite, pumice, granite, and travertine. Some of these have multiple uses in the construction industry either as aggregate or as building stone. Some sandstone is useful as building stone or, where composed of relatively pure silica, in the manufacture of glass. Limestone may likewise be quarried and used as building stone or processed and used in the manufacture of cement.

Many maps in this report show a trend of mineral occurrences in a broad belt across the State from the north-central part southwestward to the southwest corner. The presence of this belt of mineral occurrences has long been recognized (Lindgren and others, 1910). The interpretation of the belt is, at present, conjectural. It may be related to deep-seated geologic processes or it may be the fortuitous exposure of mineral deposits by erosion. However, trends of this type are a subject of serious study by geologists and the gathering of data, plotting of related data on maps, and the regional interpretation of such maps may lead to finding of other mineral occurrences.

TOPOGRAPHIC AND GEOLOGIC MAPPING

A map showing the topography of New Mexico has been published by the U.S. Geological Survey at a scale of 1 :500,000. Topographic maps showing drainage, culture, and contours drawn on lines of equal elevation have been published for many individual areas in the State (fig. 8).

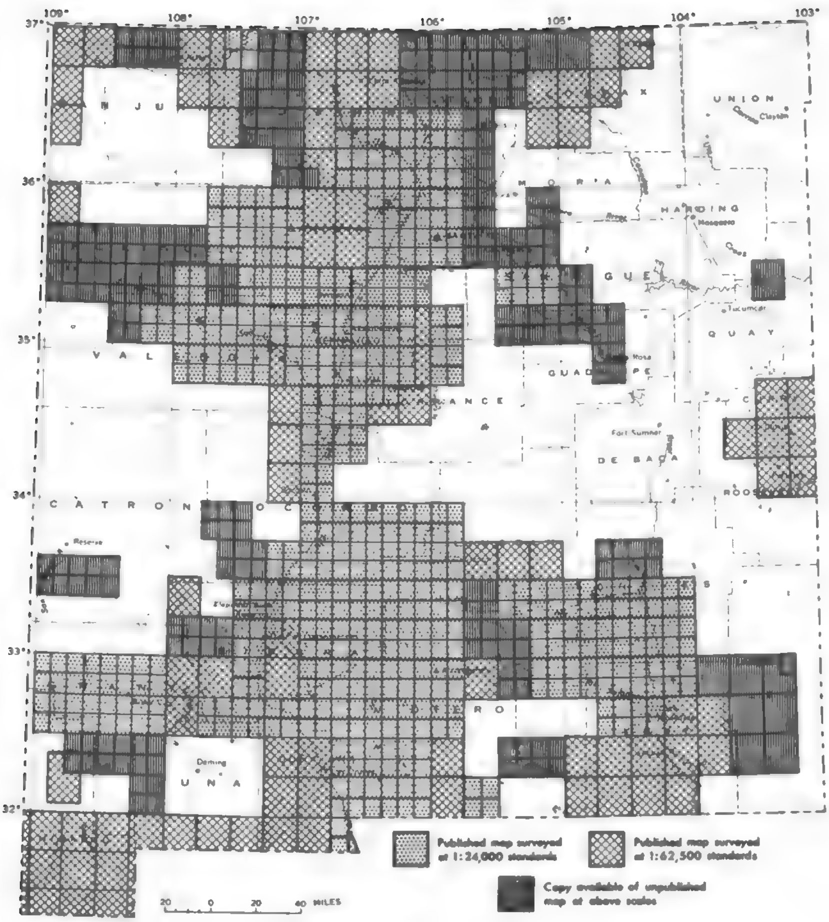

Figure 8.—Published and unpublished topographic maps in New Mexico, September 1964

Geologic maps show rock units exposed at the surface. Geologic maps have been published that cover a little more than one half the State (fig. 9). These maps are published either individually or as parts of geologic reports. They have been published mainly by the U.S. Geological Survey, the New Mexico Bureau of Mines and Mineral Resources, and the University of New Mexico. A geologic map of the

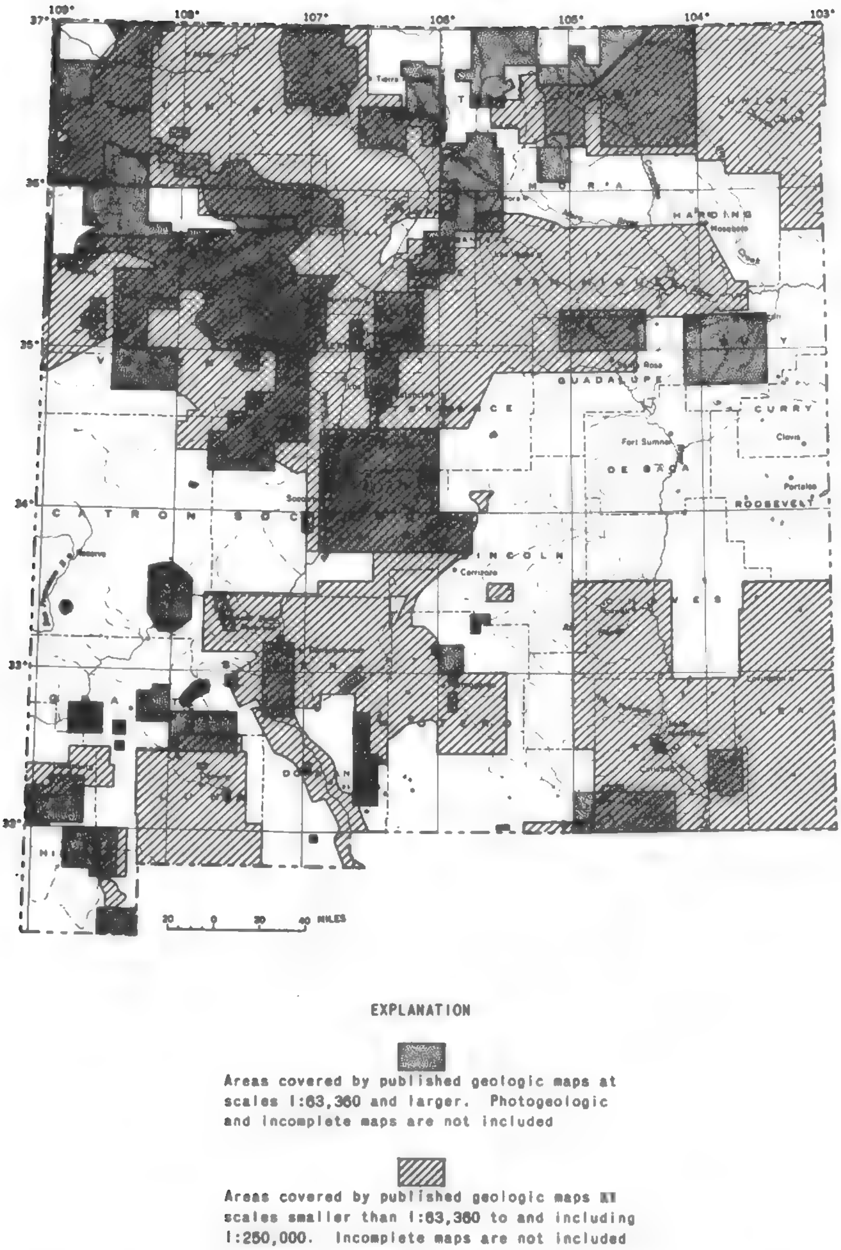

FIGURE 9.—Published geologic maps in New Mexico, September 1964.

State at a scale of 1 :500,000 has been prepared by the Geological Survey in cooperation with the New Mexico Bureau of Mines and Mineral Resources and the University of New Mexico and is now in press.

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MINERAL FUELS AND ASSOCIATED RESOURCES

OIL AND GAS DEVELOPMENT IN NEW MEXICO

(By D. S. Nutter, New Mexico Oil Conservation Commission, Santa Fe, N. Mex.)

In the United States today, New Mexico ranks fifth in the production of natural gas and seventh in the production of crude oil. This has not always been the case, however, as indicated in the following quotation from a summary of oil and gas operations in New Mexico by the New Mexico Oil and Gas Association on the occasion of the State's 50th anniversary in 1962.

In 1882, an official report of the U.S. Geological Survey reported that, "In April the New Mexico Bitumen and Oil Co., while prospecting within 6 miles of the eastern border of the Navajo reservation, and in the extreme western portion of New Mexico, discovered a flowing oil spring ; but the workmen were driven away by Navajos before they could determine the quantity of oil obtainable."

Another report, dated 1890, tells of a natural oil flow from rocks in McKinley Oounty. About a barrel a day was collected and sold to consumers in the vicinity at a rate of $10 per barrel. The report also notes that there are several places where petroleum exudes in a similar manner from the crevices in bituminous sandstone. Several localities of the State were bothered with small quantities of oil in their water wells.

Gov. M. A. Otero, in his annual report of 1902, calls specific attention to possible discoveries in several counties of New Mexico, and had this to say in regard to the southeast corner of the State : "From the Texas boundary to within a few miles of Carlsbad are fine indications of oil."

There were several test wells drilled during the first decade of the century. The most productive was in 1909 in the Pecos Valley near Artesia. This was the "Hammond," and later the "Brown" well which penetrated an oil-bearing formation between 911 and 926 feet. However, the well produced mostly water. Intermittent attempts to produce oil from the well were made. In 1911, a yield of 6 to 10 barrels a day for several months was reported. In 1919, a report of the same well indicated production of 25 barrels of oil a day, along with several hundred barrels of water. The oil was separated from the water by a series of settling tanks and sold for fuel and for smudging orchards.

"During the period of 1911-1912 there was a big rush of activity in the Seven Lakes area of McKinley County. Mr. Henry F. Brock was sinking a water well and found considerable amounts of gas and oil. As a result, some 3,000 claims were located in twenty townships nearby, and drilling began. Six wells yielded some oil and gas, but nothing in commercial quantities. By 1913, the field was practically abandoned.

Newspapers of the period between 1880 and 1920 contain many references to oil shows and many short-lived oil rushes in New Mexico. One newspaper account of 1913 told of a productive well 14 miles from Farmington, and that "The oil fever sent hundreds of people storming into the oil patch and living in tents."

Finally, in 1922, the Hogback Oil Pool in San Juan County was discovered and then, in 1924, the famous Artesia Pool of Eddy County was discovered. These were the first major discoveries of oil in the State.

Figure 10 shows an almost yearly increase in the number of wells drilled in the State. Early records indicate that 13 wells were drilled in 1924 and 180 wells were drilled the following year. With the excep-

tion of the depression years, when money was not available, and the war years, when steel was not available, there was an increase in the number of wells drilled each year to a high of 2,127 drilled in 1957. The number of wells drilled each year since 1957 has decreased due in part to a general decline in oil activity throughout the country, and in part to the fact that the recent trend toward multiple completions has reduced the number of holes required.

Figure 11 shows a steady increase from 140 producing oil wells in 1925 to 16,112 in 1962. The volume of oil produced by these wells is shown in figure 12. This production has increased in the State from 98,000 barrels in 1924 to over 111 million barrels in 1962. The value of this oil is shown by figure 13. Although there have been wide fluctuations over the years in the price paid for each barrel of oil (fig. 14), the total value of the crude oil produced has risen steadily. The 1963 edition of The Independent Petroleum Association of America publication, "The Oil Producing Industry in Your State," reports a total value of oil produced in New Mexico in 1962 of $313,079,000. The value of natural gas produced in 1962 is reported at $91,064,000. In addition, natural gas liquids valued at $43,462,000 were produced, for a total value of hydrocarbons produced in New Mexico in 1962 of $447,605,000. The IPAA further reports that 9,306 employees were engaged in the production of crude oil and natural gas in New Mexico during 1962. It estimates that the total value of all oil produced in New Mexico through 1962 is $3,828,563,000. The production has come from 8 of the 32 counties in the State. Four of these counties, San Juan, Rio Arriba, McKinley, and Sandoval, are located in the extreme northwest corner of the State, and four, Roosevelt, Chaves, Eddy, and Lea Counties, are in the extreme southeast corner of the State. Lea County, with 62 percent of the total 1962 value of oil and gas sales in New Mexico, ranks first among all counties in the United States in value of oil and gas production.

Table 5 lists the oil, gas, and gas condensate fields in New Mexico. Production information may be obtained in summary form from the annual yearbooks of Oil and Gas Development of the International Oil Scouts Association. Details of annual oil, gas, gas condensate, and water production by fields and by individual leases are contained in the Annual Reports of the New Mexico Oil and Gas Engineering Committee (Vol. I, Southeast New Mexico; Vol. II, Northwest New Mexico).

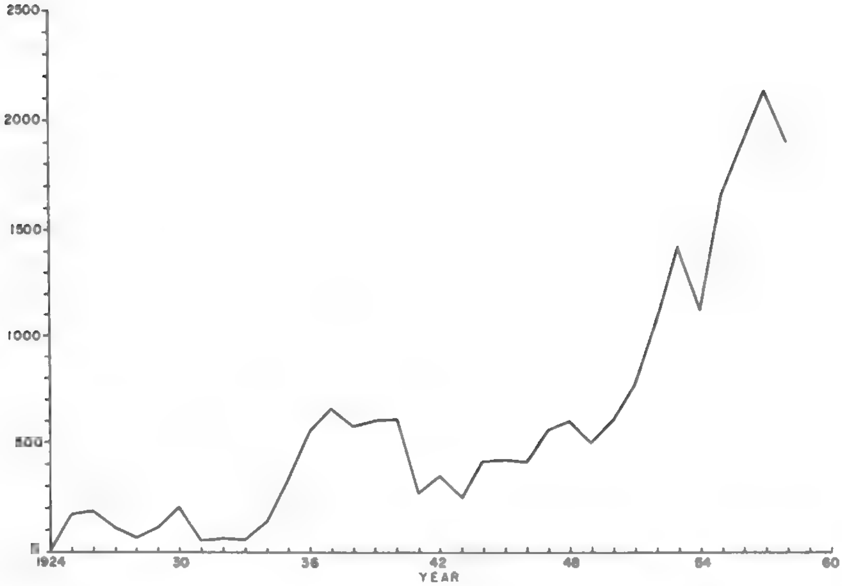

FIGURE 10.—Total oil and gas wells drilled per year in New Mexico. (Source of data: American Petroleum Institute.)

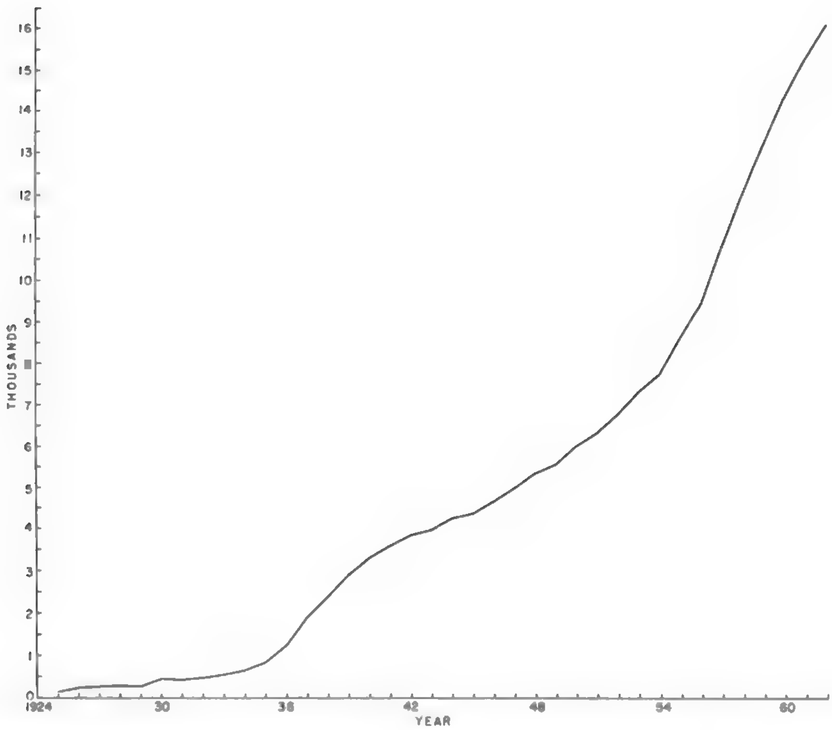

FIGURE 11.—Number of producing oil wells, in New Mexico. (Source of data: 1925–58, U.S. Bureau of Mines; 1959–62, New Mexico Oil Conservation Commission.)

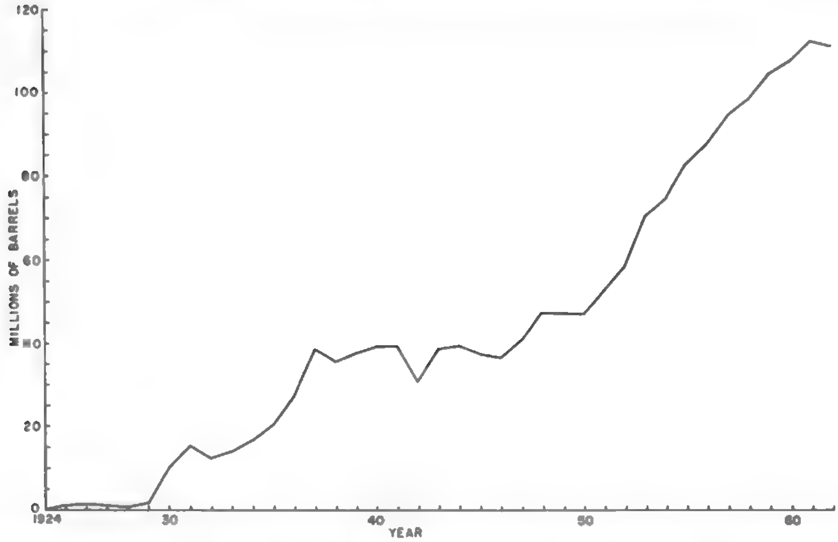

FIGURE 12.—Annual production of crude oil in New Mexico. (Source of data: American Petroleum Institute, U.S. Bureau of Mines, and New Mexico Oil Conservation Commission.)

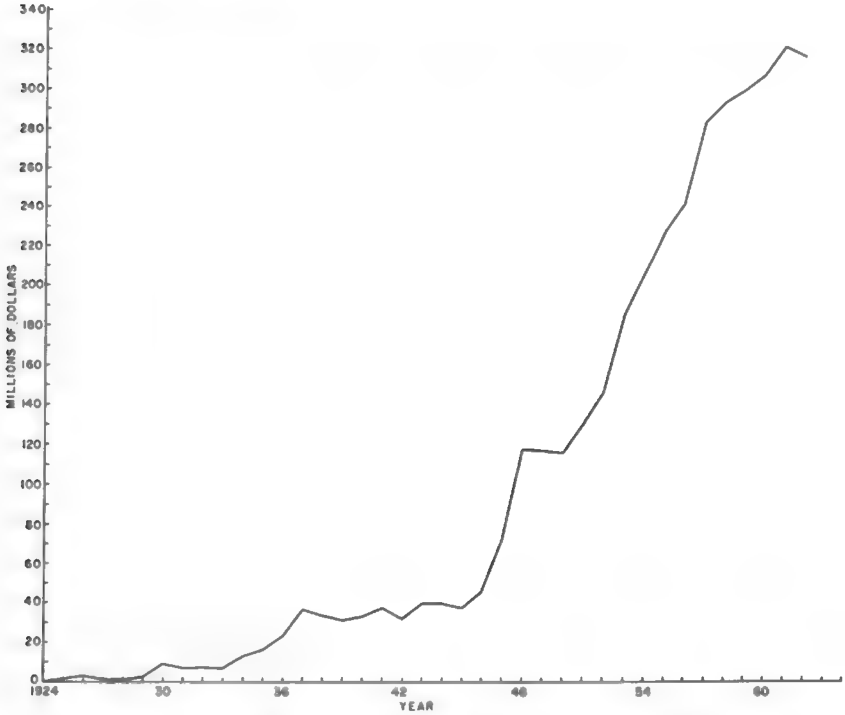

FIGURE 13.—Value of crude oil (at wellhead) produced in New Mexico. (Sources of data: 1924–58, U.S. Bureau of Mines; 1959–62, New Mexico Oil & Gas Association.)

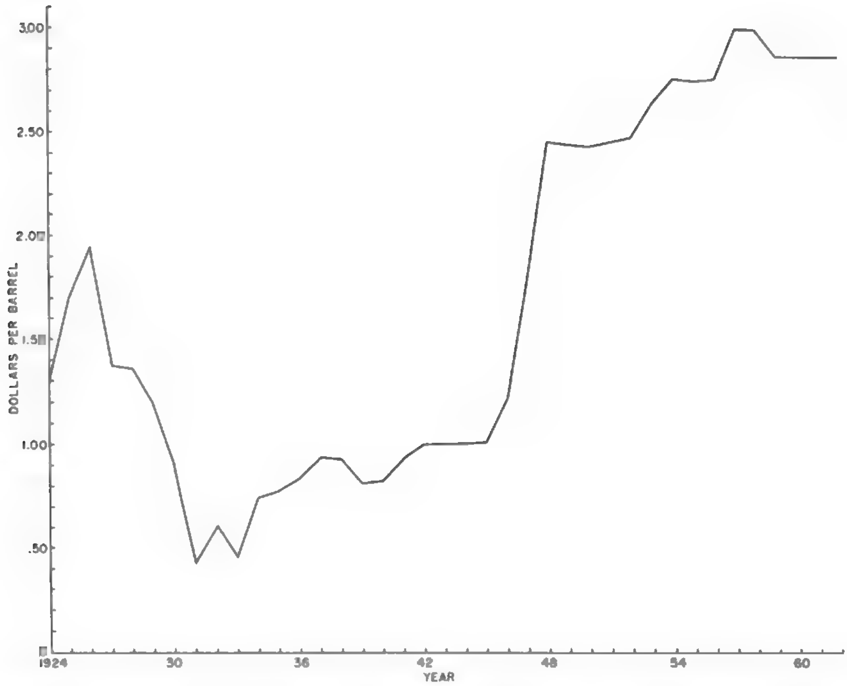

FIGURE 14.—Average price of crude oil per barrel in New Mexico. (Source of data: 1924–58, U.S. Bureau of Mines; 1959–62, New Mexico Oil & Gas Association.)

EXPLANATION FOR TABLE 5

(The following abbreviations are used in oil and gas field production tables in columns under "Reservoir Characteristics")

RESERVOIR CHARACTERISTICS

Column: Structure:

AC ------------- Anticlinal.
AC/F ---------- Anticlinal with faulting as an important factor.
AC/f ----------- Anticlinal with faulting as a minor factor.
AM----- Accumulation due to both anticlinal and monoclinal structure.
D____________ Dome.
Ds-------------- Salt Dome.
H Strata horizontal or nearly horizontal.
MC------------- Monoclinal with accumulation due to change in character of stratum.
MF ------------- Monocline with fault.
MI-------------- Monocline with accumulation against igneous barrier.
ML ------------- Monocline lens.
MU------------- Monocline unconformity.
MP ------------- Monocline with accumulation due to sealing at outcrop by asphalt.
Nose ----------- Nose or Nosing.
Sync ----------- Syncline.
SP-------------- Serpentine plug.
SL-------------- Shore line.
Terr------------- Terrace.
TF-------------- Terrace with faulting as an important factor.

Column: Character of producing formation:

An ------------- Anhydrite.
Chk------------- Chalk.
Cg-------------- Conglomerate.
Cht ------------- Chert.
CR -------------- Caprock.
Do ------------- Dolomite.
DA -------------- Arkosic dolomite.
GW ------------ Granite Wash.
Sh-------------- Shale.
Lm -------------- Limestone.
Ls -------------- Limestone, sandy.
Li _ _ _ _ _ Lime.
OL ------------- Oolitic Limestone.
SS-------------- Sandstone.
Sd--------------- Sand.
Sdy ------------- Sandy.

Column: Permeability:

P____________ Poor Presure
M--------------- Middle or medium.
Ex-------------- Excellent.
Frc -------------- Fracture.
C ---------------- Cavernous.

Column: Porosity:

por-------------- Reservoir rock is of porous type but ratio not known by author.
c --------------- Indicates reservoir rock is of cavernous type.
f ---------------- Fissure type porosity.

Column: Producing mechanism:

SGD ----------- Solution gas drive.
WD ------------- Water drive.
GCD ----------- Gas cap drive.
GS ------------- Gravity suggestion.
PM ------------- Pressure maintenance.
GI -------------- Gas injection.
WI-------------- Water injection.
WF------------- Water flood.
LPG------------- Miscible drive.
IC -------------- In situ combustion.

TABLE 5.—*Oil and gas fields in New Mexico*

FIELD; COUNTY	DISCOVERY MO - YR	GEOLOGY: PRODUCING FORMATIONS: AVG TOP FT	AVG THK *AVG PERFS IN FT	GEOLOGICAL FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Acme; Chaves	Nov 50	1975	5	San Andres	24		Do	P	7	SGD	1998	San Andres	360
Aid; Eddy	Apr 41	850	5	Yates-Sev Riv	39	H	Do	P	por	SGD	2840	San Andres	560
Allison Abo; Lea	Feb 61	8970	20*	Abo							9703	Penn	40
Allison Penn; Lea-Roosevelt	Feb 54	9670	20	Bough	49	ML	Do	280	7	WD	12125	Devonian	9200
Allison East Penn; Lea	Feb 61	9659	11*	Bough C	40						9731	Penn	240
Allison North Penn; Roosevelt	Sep 57	9652	12	Penn	49	ML	Do	280	7	WD	9750	Penn	200
Allison West; Roosevelt	Jan 62	9793	4*	Bough C	48						9840	Bough C	80
Amanda; Lea	Aug 47	7065	20	Wolfcamp			Ls	P	8	SGD	7335	Pre-Cambrian	160
Anderson; Eddy	Feb 40	2820	18	Grayburg-San And	36	MC	SS	P	5	SGD	3689	San Andres	2680
Anderson Penn, Eddy	Oct 54	11039	40	Bend		AC	Ls	P	8	SGD	12211	Devonian	320
Anderson Wolfcamp, Lea	Oct 62	9660	6*	Wolfcamp	39						13523	Devonian	80
Anderson Ranch Dev; Lea	Apr 53	13374	64	Devonian	54	AC	Do	61	5	WD	13775	Devonian	960
Anderson Ranch Penn, Lea	Jan 54	12362	10	Penn		AC	Ls				13689	Devonian	40
Anderson Ranch Wlfcp, Lea	Jul 53	9664	47	Wolfcamp	43	AC	Ls	80	10	SGD	13775	Devonian	520
Anderson Ranch East Penn; Lea	Feb 57	10960	24	Penn		AC	Ls				13642	Miss	400
Anderson Ranch North Wlfcp; Lea Created 1962 (Created out of Anderson Ranch Wolfcamp)				Wolfcamp									640
Anderson Ranch West Grayburg; Lea	Feb 62	4044	10*	Premier	38								40
Anderson Ranch West Penn, Lea	Jan 55	12512	38	Bend		AC	Ls	P	por	SGD	14015	Devonian	360
Angell Seven Rivers; Eddy	Feb 54	1114	11	Seven Rivers	30	ML	OL	P	10	SGD	4081	Delaware Mtn	440
Apache Spring Wlfcp; Chaves	Mar 55	7929	7	Wolfcamp	43		Ls	P	por	SGD	10775	Devonian	40
Arkansas Junction Dev; Lea	Jul 58	13140	34	Devonian	43	AC	Do	P	4	WD	12245	Devonian	40
Arkansas Junction Queen, Lea	Jun 60	4482	14	Queen							5230	Queen	2240
Arrow; Lea	Oct 29	2910 -3580		Queen-Yates-Seven Rivers							4350	San Andres	1120
Arrowhead Drinkard; Lea	Jun 57	6883	33	Drinkard	38	AC	Do	P	8	SGD	9930	Ellen	40
Arrowhead Grayburg; Lea	Jun 38	3680	80	Grayburg	34	AC	SS-Do	P	12	SGD	4350	San Andres	5440
Artesia; Eddy	Aug 23	1878	25	Grayburg	36	MC	SS	90	21	SGD	13260	Ellen	20360
		2500	10	San Andres		MC	Do			SGD			
	May 54	11060		Morrow (Gas)									
Atoka Grayburg; Eddy	Jul 36	980	5	Grayburg	40		SS	P	8	WD	10546	Montoya	360*
Atoka Penn; Eddy	Oct 57	8079	31	Penn	54	SL	Ls	P	por	SGD	10546	Montoya	1760
Atoka San Andres; Eddy	Mar 41	1485	10	San Andres	37	MC	Do	I	9	SGD	10546	Montoya	2880
		1710	10	San Andres									
Austin Miss, Lea	Jul 57	13194	60	Miss	52		Ls	P	por		14798	Devonian	160
Bagley Penn, Lea	Aug 49	9001	25	Penn	46	AC	Ls	P	6	SGD	11766	Pre-Cambrian	1000
Bagley Lower Penn; Lea	Oct 51	9808	10	Penn	56	AC	Ls	P	6	GCT	11075	Devonian	640
Bagley Upper Penn; Lea	Nov 55	8600		Penn	56	AC	Ls	P	5	GCD	9967	Penn	1600
Bagley Siluro-Dev; Lea	Jul 49	10790	175	Siluro-Devonian	44	AC	Do	I	4	WD	11766	Pre-Cambrian	920
Bagley East Wolfcamp; Lea	Jul 58	9994	12	Wolfcamp	43	AC	Ls	P	8	SGD	13150	Devonian	40
Bagley North Lower Penn; Lea (Formerly Bagley Lower Penn)	Jul 57	10048	18	Penn	52	AC	Ls	P	5	SGD	11750	Devonian	240*
Bagley North Upper Penn, Lea	Jun 62	9470	8*	Penn	46						11263	Devonian	160
Bagley North Wolfcamp; Lea	Sep 62	8668	16*	Wolfcamp	51						9535	Penn	40
Baish; Lea	Dec 36	2362	6	Yates		MC	SS	60	23	SGD	13573	Devonian	400
Baish Wolfcamp; Lea	May 62	9608		Wolfcamp							13657	Devonian	40
Bandana Point Penn; Eddy	Oct 59	9782	14	Morrow							12262	Ellen	160
Barber; Eddy	Feb 37	1400	5	Yates	30	AC	Do	M	15	WD	1860	Queen	600
Baum Wolfcamp; Lea	Mar 55	9840	11	Wolfcamp	42	None	Ls	P	8	SGD	9951	Wolfcamp	80
Bear Draw Queen-Grayburg-San Andres; Eddy	Feb 61	1917		Queen-Grayburg-San Andres									80
Bell Lake Bone Spring; Lea	Oct 55	8670	24	Bone Spring	43	MC	Ls	M	por	SGD	15566	Devonian	40
Bell Lake Devonian; Lea	Apr 55	14942	25	Devonian		AC	Do	M	por	WD	16806	Montoya	320
Bell Lake Penn; Lea	Oct 54	12635	23	Atoka		AC		P	por	WD	12044	Penn	320
Bell Lake North Dev; Lea	Jun 60	14368	136	Devonian	38						16906	Montoya	320
Benson, Eddy	Jul 43	1725	8	Yates	28	MC	Ls	M	17	SGD	2980	San Andres	520
Benson East Yates, Eddy	Jun 60	2098	24	Yates	34						2136	Yates	160
Benson North Queen, Eddy	Sep 54	2844	10	Queen	34	MC	SS	P	15	SGD	3556	Grayburg	320
Benson South Yates, Eddy	Dec 60	1742	27	Yates	41						3706	San Andres	520
Big Eddy Wolfcamp Eddy	Jun 62	10490	20*	Wolfcamp							14205	Devonian	160
Bishop Canyon Queen, Lea	Dec 56	4100	8	Queen	36		SS	M	15	SGD	6400	Glorieta	40
Bishop Canyon San And, Lea	Jan 59	4884	6	San Andres	27						5112	San Andres	200
Bitter Lake, Chaves	Dec 46	1247	5	San Andres							5650	Pre-Cambrian	40
Bitter Lake South San Andres, Chaves	Mar 60	860	12	San Andres	26						906	San Andres	880
Bitter Lake West San Andres, Chaves	Jul 60	760	40	San Andres	27						801	San Andres	120
Black River, Eddy	Oct 37	1943	10	Delaware	42	Terr	SS	M	24	SGD	2235	Delaware	400
Black River Penn; Eddy	Sep 58	11564	32	Penn							11920	Penn	160
Blinebry; Lea	Dec 45	5540	60	Yeso	41	AC	Ls-Do	S	8	GCD	7397	Pre-Cambrian	1920
Blinebry Gas; Lea	Nov 45	5470	50	Yeso	55	AC	Ls-Do	S	8	SGD	7397	Pre-Cambrian	23400
Blinebry West; Lea	Jul 59	5553		Blinebry									40
Bluit Penn; Roosevelt	Jan 59	9490	20	Bough C	50						12128	Devonian	1200
Bluit San Andres, Roosevelt	Feb 52	4610	50	San Andres	24	AC	Do	P	8	SGD	4867	San Andres	40
Bluit Wolfcamp; Roosevelt	Oct 59	8022	36	Wolfcamp	76	AC	Ls	76	13	WD	8762	Granite	160
Bough, Lea	May 49	9615	20	Permo-Penn	50	AC	Ls	76	13	WD	12574	Devonian	880
Bough East, Lea	Jan 50	9715	14	Permo-Penn	50	AC	Ls	76	13	WD	9729	Permo-Penn	40
Bowers, Lea	Oct 46	3130	20	Seven Rivers	42	AC	SS	30	10	SGD	8160	Pre-Cambrian	3440
Bradley, Lea	Dec 58	5302	6	Delaware Sd	39	MC	SS	M	24	SGD	6370	Delaware Sd	40
Bronco Miss; Lea	May 59	10930		Miss									240
Bronco Siluro-Dev; Lea	Nov 52	11502	103	Siluro-Devonian	44	AC	Do	P	4	WD	13848	Pre-Cambrian	480

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA: Total oil, gas, gas cond wells drilled all yrs	1962: Oil, gas, gas cond wells drld	Wells producing: Flowing	Wells producing: Artif lift	Wells producing: Gas	Wells abd: Drld dry	Wells abd: Abd producers	OIL AND GAS CONDENSATE PRODUCTION: Crude oil: Bbls in 1962	Crude oil: Cumulative bbls to 1/1/63	Condensate: Bbls in 1962	Condensate: Cumulative bbls to 1/1/63	GAS PRODUCTION: Dry gas: MCF in 1962	Dry gas: Cumulative in MCF to 1/1/63	Casinghead gas: MCF in 1962	Casinghead gas: Cumulative in MCF to 1/1/63
9	0	2	4	0			9,211	45,040						
14	1	0	11	0			6,042	106,587						
1	0	0	1	0			18,306	38,514						
125	20	85	32	0	2		4,848,772	10,844,593						
3	Comb w/Allison Penn 1961							30,764						
5	Comb w/Allison Penn 1960							116,038						
1	1	0	1	0			2,350	2,350						
1	Abd Apr 1954													
67	Comb w/Square Lake Feb 1958							1,269,650						
1	0	[illegible]	0	1					4,806	165,149	560,534	7,462,991		
1	1	1	0	0			4,979	4,979						
13	0	3	8	0			409,854	6,599,070						
1	Abd Dec 1954						0	167						
13(a)	2	2	11	0	0		297,568	2,894,060						
2	Abd Nov 1957						0	10,314						
14	2	13	1	0	2		490,718	490,718						
1	1	0	1	0			2,234	2,234						
1	Abd May 1957													
11	Comb w/Millman-East-Seven Rivers 1962							16,834						
1	Abd May 1958						0	4,813						
1	0	0	1	0			204	18,551(Produced only in April & May)						
14	3	0	0	11					388	988	1,412,720	2,644,439		
8	Comb w/Eumont Gas 1956							28,964						
1	0	0	1	0			6,632	83,622						
136	0	19	68	0			388,737	23,833,348						
500	10	85	353	0	1		930,069	13,945,196						
9	0	2	6				9,198	164,803						
11	1	0	0	14					42,338	98,104	4,210,321	9,298,040		
73	0	12	53	0			306,723	1,704,990						
1	0	0	0	1					9,010	9,010	173,199	173,199		
28	0	6	5	0			64,198	3,986,478						
4	0	0	0	4					14,588	397,218	884,861	9,189,249		
5	0	0	0	4					2,900	80,814	889,008	13,781,880		
23	0	4	16	0			834,510	16,267,373						
1	Abd 1959						0	18,760						
3	0	1	1	0			3,685	98,368						
2	2	2	0	0			18,311	18,311						
1	1	1	0	0			7,382	7,382						
10	0	0	8	0			6,044	483,931						
1	1	1	0	0			7,530	7,530						
1	0	0	0	1							NR			
15	0	0	8	0			35,100	1,898,605						
2	0	0	1	0			8,886	107,362						
2	0	0	0	0	0	1	40	884						
1	0	1	0	0			12,672	77,614						
2	0	0	0	1							838,010	1,807,200		
1	0	0	0	1			0	13,288			170,151	483,138		
1	0	0	0	1					1,100	1,106	438,863	438,863		
13	4	0	3	0	3		80	345,431						
4	0	0	4	0			6,348	17,389						
8	2	5	6	0	0	0	73,483	111,862						
13	2	5	7	0	2		181,138	211,078						
1	1	0	0	1	0	0			2,196	2,196	31,080	31,080		
1	0	1	0	0			8,552	63,710						
5	1	0	3	0			16,416	80,453						
1	Abd 1951						0	90						
22	0	0	18	0	1		7,934	28,858						
3	0	0	3	0			1,587	3,368						
18	0	0	4	0			1,315	57,320						
1	0	0	0	1(SI)							11,886	100,076		
84	0	56	16	0	0	0	730,446	2,118,874						
153	3	0	0	153					386,308	3,171,773	17,848,956	179,145,166		
1	0	1	0	0			1,085	2,480						
30	Comb w/Allison-Penn 1961							2,224,155						
1	Abd Feb 1954						0	8,171						
1	0	0	0	1					2,477	2,488	82,594	86,007		
22	0	0	4	0			5,328	4,804,900						
1	Comb w Bough 1951							57,478						
86	0	1	46	0			78,621	3,318,335						
1	Abd Jan 1962						0	8,396						
3	0	2	1				37,238	208,210						
12	0	6	6	0			700,082	6,342,631						

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TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD; COUNTY	DISCOVERY MO - YR	GEOLOGY: PRODUCING FORMATIONS: AVG TOP FT	AVG THK *AVG PERFS IN FT	GEOLOGICAL FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Bronco Wolfcamp; Lea	Dec 54	9600	36	Wolfcamp	44	AC	Ls	45	13	WD	12548	Pre-Cambrian	360
Brown; Chaves	May 42	765	5	Queen	37	MC	SS	P	15		1700	San Andres	440
Brunson; Lea	Sep 45	8050	70	Ellen	42	MU	Do	P	3	SGD	8370	Pre-Cambrian	6160
Brunson North, Lea	Sep 60	7760	78	Ellen	42	MU	Do	P	3	SGD	7906	Pre-Cambrian	160
Brushy Draw; Eddy	Dec 58	3210	6	Delaware Sd	36		SS	M	24	SGD	3266	Delaware Sd	360
Buffalo Morrow; Lea	Dec 52	13110	27*	Morrow							15041	Granite	640
Buffalo Penn; Lea	May 58	13270	35	Penn	54						14891	Devonian	160
Buffalo Wolfcamp; Lea	Oct 54	10507	12	Wolfcamp	36	AC	Ls	P	8	SGD	14916	Devonian	40
Buffalo Valley Penn; Chaves	Mar 62	8182	26	Penn							9003		640
Buffalo Valley San Andres; Chaves	Dec 59	2030	190	San Andres	34						9870	Granite	40
Burton; Eddy	Jul 34	1100	15	Yates							1607	Yates	40
Burton Penn North; Eddy (Formerly Burton Atoka North)	Mar 60	10886	19	Atoka							12429	Devonian	320
Button Mesa San And; Chaves	Jan 60	4032	10	San Andres	36						4085	San Andres	40
Byers Queen; Lea		3630		Queen		AC	SS	M	15	SGD	8160	Pre-Cambrian	800
C L R San Andres; Roosevelt	Mar 62	4600	13*	San Andres	31						9707	Bough C	80
Canyon Wolfcamp; Eddy	Jul 56	5741	12	Wolfcamp	45	MC	Do	P	por	SGD	6100	Wolfcamp	40
Caprock Queen; Chaves-Lea	Nov 40	2871 -3025	12	Queen	36	MC	SS	250	21	SGD	4385	San Andres	29240
Caprock East Devonian; Lea	Aug 51	11240	30	Devonian	43	AC	Do	M	4	WD	11336	Devonian	960
Caprock East Penn; Lea	Sep 52	10000	25	Penn	48	AC	Ls	P	8	SGD	10690	Penn	40
Caprock East Wolfcamp; Lea	Feb 53	8400	18	Wolfcamp	44	AC	Ls	P	8	SGD	11385	Devonian	200
Caprock North Queen; Lea	Jun 54	3000	30	Queen	36	MC	SS	250	21	SGD	3080	Queen	280
Carlsbad Delaware; Eddy	Feb 55	2634	5	Delaware Mtn	34	MC	SS	M	24	SGD	3206	Delaware Mtn	80
Carter San Andres; Lea	Sep 53	5815	15	San Andres	31	None	Ls	2	7	SGD	6626	Glorieta	40
Carter South San And; Lea	Feb 55	5030	10	San Andres	31	None	Do	32	6	SGD	6628	Glorieta	880
Cary; Lea	Jun 48	7140	40	Montoya	40	MU	Do	P	por	SGD	8110	Ellen	120
Cass; Lea	Dec 44	7700	86	Penn	40	AC	Do	P	10	WD	10485	Pre-Cambrian	240
Cass Draw Delaware; Eddy	Mar 60	2349	3	Delaware Sd	41						2387	Delaware Sd	40
Caudill Devonian; Lea	Sep 54	13480	25	Devonian	57	AC/F	Do	10	4	WD	14803	Devonian	680
Caudill Penn; Lea	Oct 51	11440	62	Penn		AC	Ls	P	8	SGD	11503	Penn	40
Caudill Permo-Penn; Lea	Jun 56	10292	22	Wolfcamp	42	AC	Ls	P	8	SGD	13783	Devonian	240
Cave, Eddy	May 41	2400	5	Grayburg	36	NL	SS	P	10	SGD	3080	San Andres	2800
Cave West San Andres; Eddy	Aug 58	2438	10	San Andres	34		Do	P	8	SGD	2503	San Andres	80
Cedar Hills Yates; Eddy	Apr 51	542	3	Yates	21	AC-Terr	SS	M	15	SGD	600	Yates	280
Cedar Lake Abo; Eddy	May 60	7120	24	Abo Reef	43						7497	Abo	560
Cedar Lake Atoka; Eddy	Jun 61	10910	8*	Atoka	42						11861	Morrow	40
Cedar Lake Morrow; Eddy	Feb 61	11387	26	Morrow	59						11861	Morrow	160
Cedar Point Queen; Chaves	Apr 56	2770	7	Queen	29		SS	P	15	SGD	4190	San Andres	40
Chambers Wolfcamp; Lea	Nov 55	10581	18	Wolfcamp	44	AC	Ls	36	4	SGD	14015	Devonian	80
Chisum, Chaves	Apr 50	6490	35	Siluro-Devonian	40	AC	Do	150	8	WD	6933	Pre-Cambrian	80
Chisum San Andres; Chaves	Jul 51	2028	5	San Andres	30	AC	Do	3	7	SGD	7318	Pre-Cambrian	80
Chisum Yates, Chaves	Nov 49	241	84	Yates							338	Yates	160
Cline Devonian; Lea	Dec 55	7963		Devonian		AC	Do	P	4	WD	10325	Simpson	40
Comanche; Chaves	Aug 36	1354	10	San Andres			Do	P	8	SGD	8630	Pre-Cambrian	160
Cooper Jal; Lea	27	3300 -3550	40	Yates-Sev Riv							7171	Leonard	11730
Cooper Jal Gas; Lea	May 29	3300 -3580	40	Yates-Sev Riv							7171	Leonard	2860
Corbin; Lea	Jun 38	3745	20	Queen	36	MC	SS	P	15	SGD	10018	Wolfcamp	1240
		4225	12	Queen									
Corbin Gas; Lea	Jun 38	3745	20	Queen		MC	SS	P	15	SGD	10018	Wolfcamp	160
		4225	12	Queen									
Corbin Abo; Lea	Dec 59	8552	70	Abo	37						10015	Wolfcamp	1280
Corbin Delaware; Lea	Mar 60	4720	40	Delaware	37						10015	Wolfcamp	40
Corbin Yates; Lea	Apr 52	3443	10	Yates	36	MC	SS	P	15	SGD	10015	Wolfcamp	120
Corbin South Queen; Lea	Sep 56	4379	130	Queen	36	MC	SS	P	15	SGD	4480	Queen	80
Corral Canyon Delaware; Eddy	Mar 60	3463	6	Delaware	42						3566	Delaware	280
Cotton Draw Brushy Canyon; Eddy	Jun 59	7164	16	Brushy Canyon	38						8545	Brushy Canyon	40
Coyote Queen; Chaves	Jan 38	835	25	Queen	36	SL	SS	24	15	SGD	943	Penrose	1680
Crawford Penn; Eddy	Jan 58	11060	30	Penn			Ls	P	por	SGD	11822	Penn	390
Crosby Devonian; Lea	Jun 55	8270	95	Devonian	33	AC/F	Do	36	4	WD	10830	Ellen	1716
Crossroads Devonian, Lea	May 48	12106	100	Devonian	43	AC/F	Do	M	5	WD	12750	Devonian	1840
Crossroads Miss, Lea	Mar 49	12384	16	Miss	46						12750	Miss	40
(Abd 1949 Rev Jun 60)	Jun 60	11834	72	Miss	42		Ls	P	por	SGD			
Crossroads Penn, Lea	Aug 49	9750	15	Penn	40	AC	Ls	P	7	SGD	12687	Devonian	600
Crossroads Slaughter; Lea	Aug 48	4863	16	San Andres			Do	P	por	SGD	9790	Penn	160
Crossroads East Dev; Lea	Dec 56	12173	10	Devonian	42	MC	Do	M	5	WD	12574	Devonian	290
Crossroads South Dev; Lea	Nov 54	12433	18	Devonian	43	MC	Do	21	6	WD	13314	Devonian	560
Crossroads West Dev; Lea	Nov 59	12003	20	Devonian	43						12031	Devonian	200
Crossroads West San Andres; Lea	Mar 56	4804	44	San Andres	33	AC	Do	P	por		4848	San Andres	80
Cruz Delaware; Lea	Sep 61	5095	6*	Delaware Sd	40						5227	Delaware Sd	200
Culwin; Eddy	Jul 42	3325	10	Queen	36	MP	SS	P	por	SGD	3873	Queen	1200
Culwin Yates; Eddy	Oct 59	2382	60	Yates									40
Custer Ellen; Lea	Jul 60	12730	100	Ellen	57						12966	Ellen	40
Custer Tansill; Lea	Jan 59	2605	10	Yates	33						4050	Yates	80
D-K Abo; Lea	Aug 54	7240	25	Abo	36	AC	Ls-Do	P	8	SGD	9880	Pre-Cambrian	160
D-K Drinkard; Lea	Oct 56	6900	104	Drinkard	37	AC	Do	P	8	SGD	9881	Pre-Cambrian	160
Dark Canyon; Eddy	Aug 52	1876	5	Delaware Mtn	36	NL	SS	M		SGD	1912	Delaware Mtn	40
Daugherity; Eddy	Nov 38	1800	10	Grayburg	30	AC	SS	P	10	SGD	2030	Glorieta	120
		2014	10	San Andres	33	AC	Ls-Do	P	por	SGD			
Dayton Abo; Eddy	Sep 56	3290	346	Abo	40		Ls	P	8	SGD	5437	Abo	280
Dayton Grayburg; Eddy	Jul 40	1000	36	Grayburg	36	MC	SS-Do	4	9	SGD	2545	San Andres	840
Dayton San Andres; Eddy	Jul 56	1784	30	San Andres	36	MC	Do	P	9	SGD	1881	San Andres	80
Dayton East; Eddy	Nov 44	1368	5	Grayburg	37	MP	SS	P	por	SGD	3659	Glorieta	40
Dayton East Grayburg; Eddy	Feb 60	1686	19	Grayburg	34						1635	Grayburg	320

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA 1962							OIL AND GAS CONDENSATE PRODUCTION				GAS PRODUCTION			
		WELLS PRODUCING			WELLS ABD		CRUDE OIL		CONDENSATE		DRY GAS		CASINGHEAD GAS	
TOTAL OIL, GAS, GAS COND WELLS DRILLED ALL YRS	OIL, GAS, GAS COND WELLS [illegible]	FLOWING	ARTIF LIFT	GAS	FIELD BY	ABD PROD WELLS	BBLS IN 1962	CUMULATIVE BBLS TO 1/1/63	BBLS IN 1962	CUMULATIVE BBLS TO 1/1/63	MCF IN 1962	CUMULATIVE IN MCF TO 1/1/63	MCF IN 1962	CUMULATIVE IN MCF TO 1/1/63
9	3	0	8	0			81,640	602,764						
11	0	0	0	0			2,969	20,967						
134	0	11	40	0			232,696	26,843,439						
4	Comb w/Brunson 1951							18,139						
9	3	5	2	0			21,887	70,087						
1	1	0	0	1	0						MR			
2	0	0	0	1					4,045	68,173	366,936	1,881,223		
1	0	0	1	0			1,831	66,300						
1	1	0	0	1	0				220	220	26,817	26,817		
1	0	0	82	0			0	0						
1	Temp Abd						0	2,684						
1	0	0	0	1					68	167	24,230	37,473		
1	Abd 1961						0	207						
6	0	0	0	6							184,686	8,900,677		
3	3	1	0	0	1		4,397	4,397						
1	0	0	1	0			4,864	20,221						
37	3	6	474	0	1		4,097,761	41,399,914						
24	0	0	11	0			1,131,190	18,332,806						
1	Abd 1956						0	22,818						
5	0	1	4	0			5,701	256,255						
7	Comb w/Caprock Queen Jul 1958							21,128						
2	0	0	1*	0	1		867	18,307*(No Prod Jun,Aug,Sep,Oct,Nov,Dec)						
1	Comb w/Carter South San Andres							1,123						
12	8	0	4	0			99,055	734,139						
3	0	2*	0	0			31	248,388*(Produced only in Jan)						
6	0	0	5	0			63,710	1,651,416						
1	0	0	1	0			2,261	7,487						
17	0	0	7	0			105,650	3,247,018						
1	Abd Jul 1952						0	1,631						
13	1	6	7	0			267,546	857,817						
70	0	13	31	0	1		14,379	831,691						
3	0	1	0	0			524	7,393						
9	0	0	3	0			6,613	205,143						
14	3	0	7	0	1		190,193	309,416						
1	0	0	1	0			2,187	4,447						
1	0	0	0	1							6,305	6,305		
1	0	0	1	0			220	6,982						
2	0	1	1	0			15,253	140,796						
2	0	0	1	0			16,235	431,024						
2	0	0	2*	0			1,300	37,020*(No Prod Oct,Nov,Dec)						
1	0	0	0	1							Unreported, gas used on lease only			
1	Abd Mar 1956						0	181						
4	Abd 1948						0	18,077						
283	Comb w/Jalmat 1955							31,302,995						
16	Comb w/Jalmat 1955													
31	1	0	25	0			67,062	1,081,430						
3	0	0	0	31			0	200,116						
33	9	26	0	0			881,080	1,656,443						
1	0	1	0	0			135	135						
3	0	0	2	0			1,536	32,387						
2	0	0	2	0			1,576	28,217						
5	2	0	2	0			15,286	40,063						
1	0	0	1	0			4,208	15,308						
42	0	0	31	0	3		21,660	186,798						
3	1	0	0	2							164,964	900,374		
11	0			11	1		0	52	31,348	342,387	7,516,434	49,390,906		
20	0	11	10	0			1,360,887	13,080,592						
1	0	1	0	0			7,218	16,293						
18	0	0	1	0			31,705	1,982,172						
4	0	0	1	0			736	21,300(No prod last 6 months)						
6	0	2	1	0	3		180,783	1,217,921						
7	4	6	0	0			281,700	797,767						
8	0	1	3	0			307,086	389,743						
2	0	0	1	0			6,635	12,309						
5	3	3	2	0			36,150	66,101						
38	0	Comb w/Shugart Dec 1961						182,450						
1		Comb w/Shugart Dec 1961						91,622						
1	0	0	0	1					1,002	5,444	194,611	763,343		
2	0	1	1	0			810	5,814						
4	0	2	0	0			7,649	103,408						
4	0	3	1	0			11,297	98,393						
1	0	0	1	0	1		2,818	60,916						
3	0	0	1	0			270	26,834(No prod last 6 months)						
7	0	4	1	0			12,021	64,324						
21	1	0	10	0	0	0	2,440	180,250						
1	0	0	1	0			11	1,310(Produced only in March)						
1	Abd Nov 1948						0	342						
6	0	1	6	0			7,061	38,504						

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TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD; COUNTY	DISCOVERY MO - YR	GEOLOGY: PRODUCING FORMATIONS: AVG. TOP FT.	AVG. THK. *AVG. PERFS IN FT	GEOLOGICAL FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Dean Devonian; Lea	Aug 55	13600	84	Devonian	45	AC	Do	100	7	WD	13810	Devonian	320
Dean Penn; Lea	Dec 55	11360	20	Strawn	48	AC	Ls	3	5	SGD	13866	Devonian	880
Denton; Lea	Oct 48	11267	200	Devonian	48	AC/F	Do	10	8	WD	13083	Pre-Cambrian	4880
	51	12582	180	Devonian									
Denton Miss; Lea	Dec 48	11260	35	Miss		AC	Ls	P	por	SGD	11226	Miss	40
Denton Wolfcamp; Lea	Feb 50	9286	30	Wolfcamp	46	AC	Ls	11	10	SGD	13083	Pre-Cambrian	4140
Denton North; Lea	Dec 50	12220	75	Devonian	48	AC	Do	10	8	WD	12288	Devonian	40
Denton South Devonian; Lea	Nov 55	13034	60	Devonian	50	AC	Do	P	8	WD	13284	Devonian	280
Denton South Wolfcamp; Lea	Nov 60	9488		Wolfcamp									40
Dexter San Andres; Chaves	Dec 55	1338	10	San Andres	34		Do	P	9	SGD	6811	Ellen	40
Diablo; Chaves	Aug 62	2060	32	San Andres	30						7218	Granite	40
Dickinson Devonian; Lea	May 56	12315	8	Devonian	50	AC	Do	P	4	WD	13348	Granite Wash	40
Dickinson Penn; Lea	Jan 57	11504	40	Penn			Ls	P	7	SGD	12690	Devonian	40
Dog Canyon Grayburg; Eddy	Apr 60	1383	8	Grayburg							1460	San Andres	360
Dollarhide Devonian; Lea	Apr 52	8177	33	Devonian	40	AC	Do	10	9	WD	10618	Ellen	800
Dollarhide Drinkard; Lea	Dec 51	6616	30	L Leonard	40	AC	Do	10	8	SGD	10618	Ellen	3480
Dollarhide Ellen; Lea	Aug 51	10135	75	Ellen	42	AC	Do	P	3	WD	10618	Ellen	320
Dollarhide Fusselman; Lea	Feb 52	8710	31	Fusselman	38	AC	Do	P	4	WD	10618	Ellen	400
Dollarhide Queen; Lea	Apr 52	3670	20	Queen	34	AC	SS	P	18	SGD	10618	Ellen	2760
Dos Hermanos Yates-Seven Rivers; Eddy	Jul 58	1631	5	Yates-Sev Riv	27	AC	Do	P	10	SGD	1802	Seven Rivers	1820
Double A, Abo	Dec 60	9082	47	Abo	38						9311	Abo	120
Double X; Lea	Jan 61	4914	8*	Delaware	40						8084	Delaware	600
Double X Gas; Lea	Jun 61	4871	4*	Delaware							8296	Delaware	40
Double X North, Lea	Apr 62	4974	20	Delaware	40						8084	Delaware	160
Drickey Queen; Chaves	Jun 53	2871	10	Queen							4130	San Andres	3800
Drickey South; Chaves	Nov 54	3132		Queen									
Drinkard; Lea	Oct 44	6375	50	Yeso	40	AC	Do	6	11	SGD	8000	Pre-Cambrian	22360
		6960	50	L Leonard									
Drinkard Gas; Lea	Nov 44	6750		Drinkard		AC	Do	6	11	GCD	8270	Pre-Cambrian	640
Drinkard North; Lea	Mar 46	6626	80	Leonard		AC	Do	P	11	SGD	8000	Pre-Cambrian	600
Drinkard South; Lea	Aug 46	6430	35	Leonard	40	AC	Do	P	por	SGD	10004	Ellen	120
Dublin Devonian; Lea	Sep 49	9410	5	Devonian	38	AC	Do	P	6	WD	12636	Ellen	160
Dublin Ellen; Lea	Nov 44	11880	25	Ellen	48	AC	Do	P	3	WD	12636	Ellen	40
Duffield Penn; Eddy	May 52	9616	6	Bend	52	AC/F	Ls	P	por	SGD	10186	Ellen	320
E-K Queen; Lea	Dec 54	4287	15	Queen	36	MC	SS	31	12	SGD	8013	San Andres	2760
E-K San Andres, Lea	Oct 56	5082	22	San Andres	30	MC	SS	6	13	SGD	8013	San Andres	60
		5378	12	San Andres									
E-K East Queen; Lea	Nov 57	4626	8	Queen	36	MC	SS	30	12	SGD	4876	Queen	280
Eagle Creek San And; Eddy	May 59	1264	31	San Andres	38						1396	San Andres	160
Eaves; Lea	Oct 29	3180	60	Yates-Sev Riv			SS	M	15	SGD	3642	SevRivers	1820
Eaves Gas; Lea	Jun 28	2840											
		-3250		Yates-Sev Riv							3308	Seven Rivers	1380
Echol Devonian; Lea	Aug 51	11500	80	Devonian	42	AC	Do	34	4	WD	11875	Devonian	320
Echol Wolfcamp; Lea	Mar 60	9446	16	Wolfcamp							12084	Devonian	40
Echol East Devonian; Lea	Jun 57	12021	75	Devonian	40	AC	Do	P	4	WD	12336	Devonian	340
Echol North Devonian; Lea	May 53	12067	30	Devonian	40	AC/F	Do	P	4	WD	12140	Devonian	180
		11885		Devonian									
Eidson Penn; Lea	Jan 53	10768	18	Penn	41	MC	Ls	20	9	SGD	11460	Penn	560
El Mar Delaware; Lea	Mar 59	4600	8	Delaware Ss	41	MC	SS	26	23	SGD	4600	Delaware	2380
Elliott; Lea	Mar 40	7412	30	Leonard				P	por	SGD	9884	Pre-Cambrian	40
Elliott Abo; Lea	Sep 56	7320	70	Abo	38	AN	Do	P	6	SGD	7486	Abo	120
Empire; Eddy	24	380	10	Yates-Sev Riv	32	MC	Do	M	15	SGD	12421	Ellen	7280
Empire Abo; Eddy	Nov 57	6014	18	Abo	44	AC	Do	M	8	SGD	6315	Abo	8720
Empire Atoka; Eddy	Oct 62	9742	24*	Atoka	50						10100	Miss	80
Empire Bend; Eddy	May 62	9184	44	Bend							10427	Devonian	160
Empire Paddock; Eddy	Nov 60	3075	11	Paddock	36						6318	Abo	80
Empire Penn; Eddy	Aug 53	10102	20	Penn			Ls				12431	Devonian	320
Empire Wolfcamp; Eddy	May 54	7390	40	Wolfcamp	43	None	Ls	P	8	SGD	10083	Devonian	120
Empire Yates-Sev Riv East; Eddy	Jun 61	786		Yates-Sev Riv									80
Empire Yeso; Eddy	Dec 61	2871	20*	Yeso	37						3620	Abo Reef	40
Eumont; Lea		2710		Yates	34	AC	SS	30	12	GCD	11019	Pre-Cambrian	38200
(Formerly incl in		3070		Seven Rivers	34	AC	SS			GCD			
Eunice-Monument)		3530		Queen	34	AC	SS			GCD			
		3710	28	Grayburg	36								
Eumont Gas; Lea		2710		Queen-Yates-									
(Created by Commission order)		-3330		Seven Rivers		AC	SS	30	12	GCD	11019	Pre-Cambrian	64480
Eunice-Monument; Lea	Mar 29	3630	80	Grayburg	32	AC	SS-Do	M	10	SGD	11019	Pre-Cambrian	44600
		3700											
		-3882	50	Grayburg-San And	38	AC	Do			WD			
Eunice Gas; Lea	Mar 29	3675											
		-4155		Grayburg-San And		AC	Do	P	9	GCD	9883	Pre-Cambrian	960
Eunice San Andres; Lea	Feb 61	4100		San Andres									40
Eunice South; Lea	May 30	3720	80	Seven Rivers	32	AC	SS-Do	M	10	WD	11030	Miss	11520
Eunice South Gas; Lea	May 30	3605											
		-3960		Seven Rivers		AC	SS	M	10	SGD	6203	Tubb	480
Eunice West; Lea	Aug 28	(Renamed Wilson 1948)											
Fenton; Eddy	Sep 43	2636	6	Delaware Mtn			SS	M	24	SGD	3526	Delaware Mtn	40
Field Ranch Wolfcamp; Lea	Apr 56	9466	14	Penn	43		Ls	P	7	SGD	12218	Devonian	40
Forest; Eddy	Dec 45	2632	27	San Andres	34	MC	Do	P	8	SGD	3343	San Andres	960
Foster San Andres; Lea	Jul 57	4460	11	San Andres	31		Do	P	8	SGD	4615	San Andres	40
Four Lakes Devonian; Lea	Oct 56	12505	300	Devonian	54	AC	Do	P	6	WD	13010	Devonian	340
Four Lakes Penn; Lea	May 56	10277	40	Penn	43	AC	Ls	P	14	SGD	13010	Devonian	480
Four-Mile Draw San Andres; Eddy	Mar 57	1314	16	San Andres	30						2617	Glorieta	80
Fowler; Lea	May 49	9505	175	Ellen	45	AC	Do	P	3	SGD	11198	Ellen	1120
Fowler Blinebry; Lea	Aug 50	5705	15	Clear Fork	38	AC	Do	P	8	SGD	10650	Ellen	120
	Feb 54	5602		Blinebry	38	AC	Do			SGD			
Fowler Connell; Lea	Jan 57	9711	10	Connell	40	AC/F	Do	M	10	SGD	11198	Ellen	60

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA 1962: Total oil, gas, gas cond wells drilled all yrs	Oil, gas, gas cond wells drld	Wells producing: Flowing	Wells producing: Artif lift	Wells producing: Gas	Wells abd: Drld dry	Wells abd: Abd prod wells	OIL AND GAS CONDENSATE PRODUCTION: Crude oil: Bbls in 1962	Crude oil: Cumulative bbls to 1/1/63	Condensate: Bbls in 1962	Condensate: Cumulative bbls to 1/1/63	GAS PRODUCTION: Dry gas: MCF in 1962	Dry gas: Cumulative in MCF to 1/1/63	Casinghead gas: MCF in 1962	Casinghead gas: Cumulative in MCF to 1/1/63
6	[illegible]	0	6	0			113,490	1,984,901						
24	0	3	18	0			260,783	4,490,865						
114	[illegible]	20	80	0			4,065,147	64,921,445						
1	[illegible] 1961						0	3,371						
104	0	0	87	0			1,073,670	21,775,450						
1	Comb w/Deaton 1951													
7	0	2	2	0			162,540	2,470,273						
1	0	1	0	0			38,867	68,430						
1	0	0	0	0			0	3,029						
1	1	0	1	0	0		4,189	4,189						
1	0	0	1	0	1		14,750	136,803						
1	0	0	1*	0			1	27,004 (Produced only in Jan)						
9	0	4	3	0			17,405	42,819						
20	0	0	8	0			69,186	2,850,494						
87	0	10	6	0			487,959	11,186,399						
8	0	0	2	0			115,091	3,586,740						
10	0	0	8	0			192,052	2,645,223						
69	2	0	61	0			98,997	3,129,336						
25	0	0	13	0			79,411	824,096						
3	2	3	0	0	1		96,209	167,041						
16	13	3	11	0			38,495	83,061						
1	0	0	0	SI							SI			
4	4	0	4	0	0		4,300	4,300						
78	Comb w/Caprock Queen 1955							322,022						
	[illegible] w/Caprock Queen 1955													
869	29	364	84	0			1,528,915	52,427,041						
6	0	0	0	SI										
15	Comb w/Drinkard 1961							379,600						
3	Abd Oct 1960						0	12,012						
2	0	1	1	0			7,101	39,050						
1	Abd 1947						0	30,480						
1	0	0	0	1					2	15,837	2,810	3,070,500		
69	0	0	34	0			90,839	2,044,740						
1	Abd Nov 1956						0	2,870						
7	0	4	3	0	1		61,849	145,712						
4	0	0	2	0			1,719	9,523						
36	Comb w/Jalmat & Langlie-Mattrix							6,706,253						
8	Comb w/Jalmat Gas													
6	0	1	2	0			147,943	3,780,368						
1	0	0	1	0			1,189	9,222						
6	0	1	3	0			17,159	505,298						
4	0	0	3	0			48,509	1,162,827						
14	0	3	7	0			30,003	3,204,096						
59	0	45	13	0			683,343	1,909,872						
1	Abd Nov 1961						0	8,274						
3	1	0	2	0	0	0	13,347	114,620						
182	0	0	111	0			13,945	926,798						
243	8	217	17	0	3		8,367,071	14,322,709						
1	1	1	0	0	0									
1	1	0	0	SI										
2	0	0	1	0			3,348	8,438						
1	0	0	0	1					16,084	180,611	1,300,307	10,394,330		
3	0	0	0	0			0	885,736						
2	0	1	1	0			32,774	31,361						
1	0													
706	0	227	338	0			1,616,097	52,407,142						
403	7	0	0	403					13,880	301,007	37,613,482	446,121,943		
1115	3	34	235	0			5,066,630	288,635,344						
8	0	0	0	SI			0	7,334,550						
1	0	1	0	0			2,008	5,653						
285	3	133	119	0			950,122	18,115,235						
3	0	0	0	SI							0	9,706,500		
	Renamed Wilson 1948													
1	Abd Oct 1945						0	1,020						
1	0	0	1	0			4,187	61,398						
54	0	14	4	0			9,909	480,972						
1	0	0	1	0			3,590	22,286						
3	0	0	0	3					178,170	662,188	887,481	2,706,982		
5	2	6	0	0			368,875	1,416,808						
3	0	3	1	0			289	3,042						
14	0	4	8	0			863,583	7,832,941						
3	1	1	1	0			8,044	34,580						
1	Recomp in Fowler Fusselman 1957							1,817						

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD COUNTY	DISCOVERY MO - YR	GEOLOGY: PRODUCING FORMATIONS: AVG TOP FT	AVG THK *AVG. PERFS IN FT	GEOLOGICAL FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Fowler Devonian, Lea	Jun 55	7580	22	Devonian	45	MC	Do	P	5	SGD	10868	Ellen	240*
Fowler Drinkard; Lea	Nov 53	6210	35	Leonard	42	AC	Do	P	8	SGD	8391	Fusselman	40
Fowler Fusselman; Lea	Sep 53	7410	65	Silurian	40	AC/F	Do	P	6	SGD	11198	Ellen	200
Fowler Paddock, Lea	Feb 60	4878	16	Paddock							10825		640
Fowler Upper Silurian	Feb 59	7180		Silurian									80
Fren; Eddy	36	1925	10	Seven Rivers	36	Dome	Do	P	15	SGD	4383	San Andres	5160
Fren Paddock; Eddy	May 62	4864	12*	Glorieta	37						5001	Glorieta	40
Fren Penn; Eddy	Jan 54	11962	15	Bend			Lm	P	7	SGD	13196	Devonian	480
Garrett; Lea	Apr 47	5541	20	San Andres	31	AC	Do	P	por	SGD	10085	Abo	120
Garrett Glorieta East; Lea	Nov 60	6416	14	Glorieta	26						8382	Abo	40
Garrett West San And; Lea	Nov 60	5069	268	San Andres	28						9100	Abo	40
Gem Yates; Lea	Jul 54	3243	13	Yates	31	AC	Do	30	12	WD	3523	Seven Rivers	40
Getty; Eddy	[illegible] 27	1365	10	Yates	24	AC	Do	P	por	WD	6683	Bone Spring	520
Gladiola; Lea	Nov 50	11790	50	Devonian	47	AC	Do	76	4	WD	12192	Devonian	3820
Gladiola Wolfcamp; Lea	Feb 51	9855	20	Wolfcamp	42	AC	Lm	P	8	SGD	12288	Devonian	880
Gladiola East Dev; Lea	Nov 60	12080	8	Devonian	47						12135	Devonian	80
Gladiola North Dev; Lea	Mar 56	12010	100	Devonian	47	AC	Do	76	4	WD	12118	Devonian	440
Gladiola South Wlfcp, Lea	Jul 55	9688	18	Wolfcamp	38	AC	Lm	P	8	SGD	12320	Devonian	40
Gladiola SW Atoka; Lea	Dec 60	11119	5	Penn	54						12228	Devonian	120
Gladiola SW Devonian; Lea	Mar 60	12212	8	Devonian	49						12227	Devonian	240
Glenn Castile, Eddy	Aug 52	878	5	Castile	22	ML	Do	P	por	SGD	2066	Delaware Mtn	40
Goodwin Abo; Lea	Aug 62	7477	13*	Abo Reef	41						7732	Abo Reef	80
Goodwin Drinkard; Lea	Mar 62	7347	32	L Permian	39						8200	Abo Reef	40
Grayburg Atoka; Eddy	Nov 57	10680	80	Penn			Lm	P	8	SGD	11441	Miss	100
Grayburg Paddock; Eddy	May 57	4223	17	Paddock	33	ML	SS	P	8	SGD	11422	Penn	80
Grayburg-Jackson; Eddy	Feb 29	2000		Sev Riv-Queen-									
		-3800		Grayburg-San And	36	ML	SS	P	12	SGD	13341	Ellen	30820
Grayburg-Jackson Gas; Eddy	Mar 29	2350											
		-3975		San Andres							13341	Ellen	800
	Jan 34	12400		Penn									
Grayburg-Keely; Eddy	Mar 48	3288	30	San Andres	[illegible]	MC	Do	5	6	SGD	3407	San Andres	1560
Greenwood Bone Spring; Eddy	Apr 61	(See Shugart		Bone Spring)									
Greenwood Wolfcamp; Eddy	Mar 61	(See Shugart		Wolfcamp)									
Gross Devonian, Lea	Jun 56	12338	6	Devonian	[illegible]	AC	Do	P	por	WD	12350	Devonian	40
Hackberry Yates, Eddy	Oct 53	2047	6	Yates	22	Terr	Do	P	por	SGD	2110	Yates	200
Hackberry Sev Riv; Eddy	Oct 61	2050		Seven Rivers									120
Hackberry North Yates, Eddy	Nov 59	2123	42	Yates	33						3861	Penrose	960
Halfway, Lea	Oct 39	2495	3	Yates	[illegible]	AC	Do		15	SGD	3763	Queen	640
Hardy, Lea	Mar 36	3710	25	Grayburg	35	ML	SS	M		SGD	10018	Simpson	2040
Hare, Lea	Jul 47	7780	50	Simpson	[illegible]	MD	SS	M	13	SGD	8700	Simpson	3800
Hare South, Lea	Sep 47	7360	90	Simpson	40	MD	SS	M	13	SGD	7651	Pre-Cambrian	120
Harkey, Eddy	Jan 58	10917	93	Penn			Lm	P	por		13654	Devonian	320
Harrison; Lea	Jul 49	5015	25	Yeso							5075	Glorieta	40
Henshaw, Eddy	Feb 40	3150	10	Grayburg-San And	36	Dome	Do	P	10	SGD	3850	San Andres	160
Henshaw Devonian, Eddy	Jul 60	11680	12	Devonian	54						13072	Granite	160
Henshaw Wolfcamp Eddy	Jun 61	8753	10*	Wolfcamp	40						10000	Penn	200
Henshaw West Grayburg; Eddy	Sep 56	2745	189	Premier	36	Dome	SS	P	por	SGD	3623	San Andres	2400
High Lonesome, Eddy	Nov 39	1775	10	Queen	34	ML	SS	14	12	SGD	3105	San Andres	2440
High Lonesome Sev Riv, Eddy	Apr 56	1219	31	Seven Rivers		ML	SS	P	10	SGD	1904	Seven Rivers	40
High Lonesome South; Eddy	Feb 40	2120	10	Grayburg			Do	P	por	SGD	2845	San Andres	160
Hightower; Lea	Aug 49	10100	78	Siluro-Devonian	39	AC	Do	M	4	WD	11190	Pre-Cambrian	80
Hightower Permo-Penn; Lea	Jan 50	8660	30	Permo-Penn	64	AC	Lm	P	por	SGD	10620	Devonian	520
Hightower East Dev; Lea	Feb 59	12890	25	Devonian	58						13103	Devonian	160
Hightower East Penn; Lea	Feb 59	10218	28	Permo-Penn	41						13103	Devonian	40
Hills; Eddy	Jan 58	2460	3	San Andres	25		Do	P	por	SGD	3000	Bone Spring	40
Hobbs; Lea	Dec 28	4060	100	San Andres	34	AC	Lm-Do	50	15	WD	11211	Pre-Cambrian	14860
Hobbs Gas; Lea	Jun 28	3850											
		-4275		Grayburg-San And		AC	Lm	50	15		8010		640
Hobbs Drinkard; Lea	Apr 52	6430	10	Leonard	35	AC	Do	P	8	SGD	8140	Pre-Cambrian	40
Hobbs East Blinebry, Lea	Dec 51	6408	14	L Leonard	38	AC	SS	P	por	SGD	6433	Leonard	40
Hobbs East San Andres; Lea	Oct 51	4449	15	San Andres	34	AC	Do	300	25	WD	6433	Leonard	1040
Hobbs East Sev Riv, Lea	Aug 53	3852	14	Seven Rivers	32	MC	SS	P	por	SGD	4505	San Andres	40
House, Lea	Feb 49	7010	80	Leonard	39	ML	Do	P	por	SGD	10014	Pre-Cambrian	560
House Gas, Lea		7025		Drinkard		ML	Do	P	por	SGD	8112	Devonian	160
House San Andres; Lea	Jan 50	4276	30	San Andres	34	MC	Do	P	por	SGD	10014	Pre-Cambrian	440
House Tubb, Lea	Sep 51	6760	20	Yeso		MC	SS	P	por	SGD	7170	Leonard	320
Hume Queen, Lea	Dec 56	3950	21	Queen	35	MC	SS	P	15	SGD	14093	Devonian	800
Hume West Queen; Lea	Jun 62	3927	18*	Queen	33						3972	Queen	120
Imbe Penn, Lea	Aug 62	9862	8*	Bough C	44						10500	Penn	240
Jackson Abo; Eddy	Mar 61	6630	30*	Abo Reef	44						7050	Abo Reef	400
Jalco; Lea		2985		Yates	29						7171	Leonard	27360
		3200		Seven Rivers									
Jalmat; Lea		2985				MC	SS-Do	3	17	SGD			
(Created by Commission order)		-3300		Yates	29	MC	SS-Do	49	17	SGD	7171	Leonard	24120
		3300											
		-3550		Seven Rivers									
Jalmat Gas; Lea		2900											
(Created by Commission order)		-3600		Yates-Sev Riv		MC	SS-Do	P	por	SGD	7171	Leonard	66720
Jalmat-Rhodes West, Lea		2900											
(Created by Comm order 1957)		-3600		Yates-Sev Riv		MC	SS-Do	P	por	SGD	7171	Leonard	3200
Jenkins San Andres; Lea	May 59	4646	20	San Andres	19						10025	Penn	80
Jenkins Wolfcamp; Lea	Apr 60	9604	10	Wolfcamp	48						9633	Wolfcamp	240
Jennings Delaware; Lea	May 56	4621	3	Delaware Sd	41	ML	SS	M	24	SGD	4658	Delaware Sd	40
Justis Blinebry; Lea	Mar 58	5154	16	Blinebry	38	AC	Lm-Do	P	4	SGD	7600	McKee	3040
Justis Drinkard, Lea	Dec 57	5930	20	Drinkard	38	AC	Do	P	8	SGD	7520	McKee	1000
Justis Ellen, Lea	Jun 57	8115	41	Ellen	41	AC	Do	P	4	WD	8235	Ellen	1000
Justis Fusselman; Lea	Jan 58	7004	44	Fusselman	38	AC	Do	M	4	WD	8635	Ellen	1200
Justis Glorieta, Lea	Feb 46	4744	79	Glorieta		AC	SS	P	8	SGD	9594	Pre-Cambrian	600
Justis McKee; Lea	Oct 57	7325	47	McKee	42	AC	SS	M	15	SGD	7520	McKee	600
Justis Montoya; Lea	Jun 58	7002	15	Montoya	38	AC		M	4	WD	8210	Ellen	320

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA: TOTAL OIL, GAS, GAS COND WELLS DRILLED ALL YRS	1962: OIL, GAS, GAS COND WELLS DRLD	WELLS PRODUCING: FLOWING	WELLS PRODUCING: ARTIF LIFT	WELLS PRODUCING: GAS	WELLS ABD: DRLD DRY	WELLS ABD: ABD PRODUCERS	CRUDE OIL: BBLS IN 1962	CRUDE OIL: CUMULATIVE BBLS TO 1/1/63	CONDENSATE: BBLS IN 1962	CONDENSATE: CUMULATIVE BBLS TO 1/1/63	DRY GAS: MCF IN 1962	DRY GAS: CUMULATIVE IN MCF TO 1/1/63	CASINGHEAD GAS: MCF IN 1962	CASINGHEAD GAS: CUMULATIVE IN MCF TO 1/1/63
6	0	3	1	0			40,096	312,689						
1	0	0	1	0			3,701	45,870						
5	0	0	1	0			12,743	866,872						
4	2	0	0	3							301,200	663,836		
3	0	0	2	0			6,834	41,683						
137	1	16	91	0			88,800	3,502,196						
1	1	0	1	0	0		2,781	2,781						
3	0	0	0	3					3,016	134,273	434,600	5,270,163		
3	0	0	1	0			1,353	30,501						
1	0	0	1	0			80	703(Abd Jul 1962)						
1	0						NR							
1	0	0	0	0			0	19,720						
13	1	0	10	0			34,851	1,618,424						
90	1	9	73	0	1		4,173,903	38,521,422						
34	1	0	13	0	0		72,914	3,060,677						
1	0	0	1	0	1		25,209	53,832						
11	Comb w/Gladiola Dec 1957							249,507						
1	0	0	1	0			6,410	116,754						
2	0	2	0	0			40,099	123,181						
6	0	5	1	0	1		447,017	949,503						
1	Abd 1956						0	1,716						
1	1	1	0	0	0		2,718	2,718						
1	1	1	0	0			8,142	8,142						
1	0	0	0	1					19,818	119,208	881,701	3,306,833		
2	0		SI				0	10,172						
609	4	113	530				1,438,306	44,761,037						
5	0	0	0	3					88	2,088	106,168	730,700		
30	Comb w/Grayburg-Jackson Oct 1960							992,316						
1	Abd Aug 1956						0	3,672						
6	1	0	3	0	1		2,820	23,369						
3	0	0	3				16,484	18,416						
34	10	2	21	0			70,291	144,231						
16	0	0	5	0			9,147	822,252						
51	Comb w/Eumont 1957							2,621,502						
80	0	14	46	0			256,468	13,798,494						
3	0	0	1	0			1,813	190,115						
2	0	0	0	SI							0	78,544		
1	Abd Jul 1949						0	10,334						
4	1	1	2	0			5,249	45,139						
2	0			SI						12	0	7,500		
5	4	2	0	0	1		122,101	122,101						
73	0	46	28	0	1		258,843	1,932,871						
61	1	12	48	0	0		221,506	1,663,798						
1	0	0	0	0	0	0	0	592						
4	Abd Apr 1949						0	12,274						
2	0	0	1	0			18,104	888,067						
7	0	3	2	0			32,800	438,748	0	80,000	0	1,307,342		
1	0	0	0	SI					0	6,613	0	91,293		
1	0	0	1	0			8,113	44,387						
3	0	0	0	0			0	381						
364	4	164	174	0	1		3,267,833	173,325,761						
6	0	0	0	SI					0	2,231	0	121,371		
1	0	0	1	0			4,880	44,538						
1	0	0	1	0			6,818	81,353						
26	0	1	21	0			211,796	2,306,365						
1	0						NR							
14	0	4	8	0			58,140	1,336,701						
1	0	0	0	SI										
10	0	2	4	0			13,706	306,102						
2	0	0	0	2					964	13,175	86,100	720,000		
20	0	1	16	0			78,606	463,959						
3	3	0	2	0			2,545	2,545						
3	3	0	1	0			8,454	8,454						
10	0	11	0	0	0		134,411	147 863						
	Comb w/Jalmat 1955													
603	4	163	251	0			1,390,346	56,230,838						
418	0	0	0	417					15,316	317,741	56,836,465	1,086,174,860		
20	0								0	377	4,041,268	148,284,832		
2	0	1	0	0	1		..683	9,057						
3	0	2	0	0			62,886	152,186						
1	0	0	0	0			0	1 575						
76	14	66	8	0	0		848,644	2,213 973						
27	Comb w Justis Tubb-Drinkard Nov 1960							871 182						
25	0	15	1	0			569,344	2 925,716						
30	1	24	6	0			683,354	2,730,634						
15	4	0	0	14			6,750	39,107			3,080,583	27,867,583		
15	0	12	2	0			131,080	1,014,418						
13	0	10	2	0			281,375	1,184,502						

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TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD; COUNTY	DISCOVERY MO - YR	GEOLOGY: PRODUCING FORMATIONS: AVG TOP FT	AVG THK *AVG PERFS IN FT	GEOLOGICAL FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Justis Paddock; Lea	May 56	4960	35	Paddock	39						8870	Ellen	160
Justis Tubb-Drinkard; Lea (Created by Comm order Nov 60)				Tubb-Drinkard									3080
Justis North Blinebry, Lea	Oct 61	5270	124*	Blinebry	37						6050	Drinkard	440
Justis North Devonian; Lea	Dec 61	7064	20*	Devonian	38						8931	Ellen	520
Justis North Drinkard, Lea	Aug 61	5958	38*	Drinkard	38						8565	Ellen	560
Justis North Ellen, Lea	Aug 61	8458	24*	Ellen	47						8565	Ellen	280
Justis North Fusselman, Lea	Jun 61	7000	40*	Fusselman	42						8700	Ellen	480
Justis North McKee, Lea	Aug 61	7928	44*	McKee	47						8565	Ellen	400
Justis North Montoya Lea	Apr 62	7070	50*	Montoya	36						8550	Ellen	80
Justis North Waddell, Lea	Sep 61			Waddell									80
Kemnitz Cisco, Lea	Oct 57	11446	30	Cisco	44	AC	Lm	P	8	SGD	11596	Penn	160
Kemnitz Penn, Lea	Oct 56	11219	46	Penn	43	AC	Lm	P	8	SGD	14797	Devonian	80
Kemnitz Wolfcamp, Lea	Dec 56	10742	38	Wolfcamp	39	AC	Lm	P	8	SGD	13000	Penn	1480
King Devonian, Lea	Mar 56	12439	300	Devonian	46	AC	Do	M	4	WD	12850	Devonian	560
King Penn, Lea	Apr 60	10708	25	Penn	38						13145	Devonian	40
King Wolfcamp, Lea	Nov 51	10126	30	Wolfcamp	38	AC	Lm	P	8	SGD	13145	Devonian	240
King Camp Devonian, Chaves	Jul 59	10222	30	Devonian	55						10360	Devonian	40
Knowles, Lea	May 49	12446	150	Devonian	47	AC/T	Do	23	6	WD	12656	Devonian	280
Knowles South Devonian; Lea	May 54	12140	40	Devonian	47	AC	Do	26	4	WD	12656	Devonian	1120
Laguna Seven Rivers; Lea	May 58	4104	23	Seven Rivers		AC	SS	P	10	SGD	4360	Queen	160
Lakewood San Andres, Eddy	Sep 56	1376	24	San Andres			Do	P	por	SGD	2478	Glorieta	40
Lane Penn, Lea	Jul 56	9802	8	Penn	40	AC	Lm	P	5	SGD	9865	Penn	120
Lane Wolfcamp; Lea	Dec 55	9840	14	Wolfcamp	40	AC	Lm	100	10	SGD	12637	Devonian	360
Lane Middle Penn; Lea	Oct 62	9650	4*	Bough C	40						9836	Devonian	40
Lane South Penn, Lea	Mar 62	9668	11*	Bough C	40						9846	Bough C	320
Langlie-Mattix; Lea	Jul 35	3350 -3500		Sev Riv-Queen	36	AC	SS	M	15	SGD	11198	Ellen	48280
Langlie-Mattix Gas; Lea	Jan 29	2870 -3680		Queen-Yates-Seven Rivers		AC	SS	M	15	SGD	11014	Pre-Cambrian	9920
Langmat, Lea		2880		Yates							11198	Ellen	29120
		3155		Seven Rivers									
Lazy J; Lea	Oct 52	9580	30	Wolfcamp-Penn	43	None	Lm	S	6	SGD	13440	Devonian	1600
Lea Bone Spring; Lea	Oct 60	9480	70	Bone Spring	42						14735	Devonian	480
Lea Devonian; Lea	Jul 60	14347	124	Devonian	56						14735	Devonian	480
Lea Penn; Lea	Apr 61	13034	20	Penn							14 19	Devonian	480
Lea Yates; Lea (Abd 1947, Rev Jan 57)	29	3570	15	Yates	29	ML	Sd	P	por	SGD	3768	Seven Rivers	80
Leamex Penn; Lea	Nov 56	11316	36	Penn	37	AC	Lm	P	por	SGD	16842	Granite	240
		10862	54	Penn									
Leamex Wolfcamp; Lea	Feb 61	10622	100*	Wolfcamp	40						15390	Devonian	160
Leo, Eddy	Aug 39	3250	10	Grayburg	35	ML	SS	P	12	SGD	3860	San Andres	480
Leo East Grayburg; Eddy	May 56	3646	34	Grayburg	33	ML	SS	P	12	SGD	3750	Grayburg	40
Leo South Grayburg; Eddy	Jan 58	2846	14	Grayburg	35	ML	SS	P	12	SGD	4497	Delaware Sd	160
Leonard; Lea	Jun 48	3430	10	Seven Rivers	40	AC	SS	P	15	SGD	3511	Queen	80
Leonard South; Lea	Feb 50	3438	2	Queen	40	AC	SS	P	por	SGD	3500	Queen	600
Lightcap; Chaves	May 60	7988	20	Siluro-Devonian	52	AC	Do	37	10	WD	8326	Pre-Cambrian	80
Little Lucky Lake Devonian; Chaves	Oct 58	11680	84	Devonian	56	AC	Do	M	6	WD	12298	Ellen	200
Little Lucky Lake Ellen; Chaves	Oct 58	12068	38	Ellen	50						12298	Ellen	160
Littman San Andres; Lea	Jul 51	4321	20	San Andres	31	None	Do	P	8	SGD	4394	San Andres	360
Loco Hills; Eddy	Jan 39	2420	20	Grayburg	36	ML	SS	50	20	SGD	3750	San Andres	13320
		2925	30	San Andres									
Loco Hills Abo; Eddy	Aug 60	6870	60	Abo Reef	44						6945	Abo	320
Loco Hills Queen; Eddy	Apr 40	2200	15	Queen	36	ML	SS	P	por	SGD	3100	Grayburg	120
Loco Hills South San Andres; Eddy	Nov 56	3034	26	San Andres	36	ML	Do	P	8	SGD	4520	Delaware Sd	40
Logan Draw; Eddy	Mar 47	1709	30	San Andres	41		Do	P	por	SGD	2036	San Andres	80
Lone Wolfcamp; Chaves	Aug 53	7774	38	Wolfcamp	43	MC	Lm	P	por	SGD	9298	Pre-Cambrian	40
Los Medanos Atoka; Eddy	May 58	13820	9	Penn	66	AC	SS	M	por	GCD	17555	Ellen	160
Loving Delaware; Eddy	Mar 58	3444	10	Delaware Sd	43						2455	Delaware Sd	80
Lovington, Lea	Jan 36	4600	80	San Andres	33	AC	Do	P	4	SGD	14153	Pre-Cambrian	2360
Lovington Abo, Lea	Dec 51	8117	125	Abo	38	AC	Do	M	6	WD	14153	Pre-Cambrian	1880
Lovington Paddock; Lea	Jun 52	6156	25	Glorieta	33	AC	Do	P	8	SGD	14153	Pre-Cambrian	3760
Lovington San Andres; Lea	Jan 39	3200 -3900		San Andres	33	AC	Do	P	4	SGD	4980	San Andres	320
Lovington Tubb; Lea	Dec 52	7840	15	Leonard	40	AC	Do	P	por	SGD	11254	Penn	40
Lovington Wolfcamp; Lea	Dec 52	10148	15	Wolfcamp	40	AC	Lm	P	por	SGD	12751	Devonian	40
Lovington East Penn; Lea	Mar 51	11080	60	Strawn	43	AC	Lm	P	por	SGD	12871	Devonian	280
Lovington West, Lea	Jun 44	4700	50	San Andres	38	AC	Do	P	4	SGD	5175	San Andres	2320
Lovington West Penn, Lea	Mar 53	11438	15	Strawn		AC	Lm	P	por	SGD	11984	Penn	40
Lovington West Plains; Lea	May 52	12880	30	Penn			Lm	P	por	SGD	14763	Devonian	40
Lucky Lake Queen; Chaves	Jun 56	1894	11	Queen			SS	M	15	SGD	1973	Queen	40
Lusk, Eddy-Lea	Nov 41	2540	10	Yates	35	MC	SS-Do	P	por	SGD	4016	Queen	520
Lusk Bone Spring, Lea	Oct 60	8750	18	Bone Spring	39						11232	Strawn	80
Lusk Penn, Lea	Apr 61	12380	18*	Morrow							13974	Devonian	640
Lusk Strawn; Lea	Oct 60	11168	25	Strawn	50						11232	Strawn	240
Lusk East, Lea	Jan 42	2620	13	Yates	25	MC	SS	P	por	SGD	4016	Queen	240
Lusk South Yates; Lea	Sep 57	2486	20	Yates	27	MC	SS	P	por	SGD	2770	Yates	40
Lusk West, Eddy	Dec 41	2460	10	Yates	27	AC	SS	P	por	SGD	2769	Seven Rivers	200
Lynch, Lea	May 29	3675	17	Yates-Sev Riv	31	MC	Do	M	c	WD	4046	Seven Rivers	2320
Lynch Middle Yates; Lea	May 57	3512	15	Yates	30	MC	Do	P	c	SGD	3691	Seven Rivers	160
Lynch North, Lea	Aug 29	3660	18	Yates	30	MC	Do	M	c	WD	4769	Grayburg	120
Magruder Yates, Eddy	Feb 53	570	2	Yates	18	AC	SS	P	por	WD	626	Yates	360
Malaga, Eddy	Jun 51	2774	14	Delaware Mtn	42	AC	SS	55	24	SGD	2914	Delaware Mtn	960
Malaga Delaware North; Eddy	Aug 54	4678	6	Delaware Mtn	34						8153	Bone Spring	40
Malaga West; Eddy	Aug 52	2300	8	Delaware Mtn	42	AC	SS	M	24	SGD	2311	Delaware Mtn	40
Maljamar; Eddy-Lea	[illegible] 26	3600 -4050	30	Grayburg-San And	37	AC	SS-Do	47	11	SGD	13673	Devonian	21760

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA 1962: Total oil, gas, gas cond wells drilled all yrs	Oil, gas, gas cond wells drld	Wells producing: Flowing	Wells producing: Artif lift	Wells producing: Gas	Wells abd: Drld dry	Wells abd: Abd prod. wells	Oil and gas condensate production: Crude oil, bbls in 1962	Crude oil, cumulative bbls to 1/1/63	Condensate, bbls in 1962	Condensate, cumulative bbls to 1/1/63	Gas production: Dry gas, MCF in 1962	Dry gas, cumulative in MCF to 1/1/63	Casinghead gas, MCF in 1962	Casinghead gas, cumulative in MCF to 1/1/63
4	0	4	0	0			35,171	75,344						
77	9	60	14	0	0		709,974	3,564,987						
11	10	11	0	0			84,066	84,066						
13	13	6	2	0	1		77,559	77,559						
14	13	13	2	0			70,493	70,493						
7	0	5	2	0			149,937	155,874						
12	11	12	2	0	1		276,901	281,790						
10	8	10	0	0			183,834	183,934						
2	2	1	1	0	0		12,204	12,204						
2	2	2	0	0			10,486	10,486						
2	0	2	0	0			19,818	309,720						
2	0	SI	0	0			0	135,309						
37	0	9	21	0			1,534,125	8,987,377						
14	0	8	2	0			380,064	3,467,565						
1	0	SI	0	0			0	5,238						
8	0	0	6	0			18,806	465,170						
1	0	0	0	0	0	1	0	21,365						
7	0	0	7	0			113,645	3,362,017						
14	0	4	10	0			380,619	4,054,132						
1	Abd 1960						0	142,200						
1	0	0	SI	0			0	732						
3	0	0	2	0	0	1	22,783	417,484						
9	0	8	1	0	0	0	9,784	1,048,164						
1	1	1	0	0	0	0	1,317	1,317						
8	8	8	0	0	0	0	88,773	88,773						
1207	17	382	302	0	4	0	3,130,543	38,603,866						
62	Comb w/Jalmat Gas 1959 Comb w/Jalmat Gas 1953									6,164		74,489,493		
40	1	2	17	0	0	0	146,714	2,164,848						
6	1	6	0	0	0	0	281,830	430,274						
6	1	6	0	0	0	0	701,304	1,113,366						
3	3	0	0	3					47,087	47,087	1,284,813	1,284,813		
2	0	0	1	0	0	0	861	78,506						
6	0	1	2	0	0	0	47,804	461,104						
2	0	1	1	0	0	0	30,739	31,582						
12	1	0	10	0	2		7,031	363,651						
1	Comb w/Shugart N Queen Grayburg Apr 1959							2,768						
4	0	1	2	0	0	0	2,998	24,486						
2	0	0	2	0	0	0	1,455	42,409						
15	0	5	6	0	0	0	18,431	499,013						
2	0	2	0	0	0	0	8,447	111,399						
8	0	4	0	0	1	0	244,034	856,116						
1	0	0	0	SI	0	0			0	11,177				
9	0	1	7	0	0	0	18,440	288,340						
332	23	35	198	0	1	0	1,609,522	20,781,148						
8	2	6	0	0	1	0	107,412	180,954						
2	0	0	1	0	0	0	527	21,123						
1	0	0	1	0	0	0	818	5,069						
2	0	0	2	0	1	0	1,809	8,041						
1	0	0	1	0	0	0	2,972	112,369						
1	0	0	0	1	0	0			1,033	3,235	48,218	281,161		
2	Abd 1960						0	125						
58	0	0	40	0	0	0	113,100	8,442,299						
47	0	28	20	0	0	0	1,272,889	14,963,296						
93	0	2	89	0	0	0	350,428	7,305,702						
2	0	0	0	0	0	0					0	1,896,809		
1	Abd Feb 1963						0	2,231						
1	Abd 1961						0	80,631						
7	0	1	2	0	0		59,906	1,490,331						
59	0	5	51	0	0	1	113,917	7,057,181						
1	Abd Apr 1953						0	4,200						
1	Abd Jul 1963								0	4,012	0	62,368		
1	0	0	0	0			0	200						
13	1	1	8	0	0	1	13,734	283,829						
1	0	SI	0	0			0	14,069*						
1	0	0	0	SI							SI			
2	0	3	0	0	0	0	297,283	436,149						
6	Abd Jan 1947						0	89,501						
1	0	0	1	0	0	0	803	5,947						
5	0	0	1	0	0	0	1,062	24,468						
88	4	8	43	0	1		389,438	10,921,834						
4	0	0	1	0	0	0	2,704	28,281						
3	1	0	2	0	0	0	8,549	231,467						
9	0	Shut In		0	0		0	11,091						
24	0	0	20	0	0	0	18,972	882,292						
1	0	0	1	0			1,007	14,465*						
1	Abd 1963						0	363						
844	23	243	296	0	1		2,741,333	45,308,613						

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD, COUNTY	DISCOVERY MO - YR	GEOLOGY: PRODUCING FORMATIONS: AVG. TOP FT	AVG. THK *AVG. PERFS IN FT	GEOLOGICAL FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Maljamar Abo; Lea	Sep 54	8800	8	Abo	40	AC	Do	M	8	WD	13086	Devonian	40
(Abd 1954, Rev 1960)	Nov 61	8840	60	Abo Reef	42								
Maljamar Devonian; Lea	Jan 52	13348	35	Devonian	46	AC	Do	P	por	WD	13086	Devonian	80
Maljamar Paddock; Lea	May 50	5271	15	Leonard	38	AC	Do	13	11	SGD	8441	Leonard	280
Maljamar Queen; Lea	Jan 50	3136	20	Queen		AC	SS	P	por	SGD	4216	San Andres	480
Maljamar Strawn, Lea (Abd Jul 54 Rev 1962)	May 54	11616	6	Strawn				P	por	SGD	13030	Devonian	40
Maljamar Wolfcamp; Lea	Apr 61	10380	10*	Wolfcamp	40						12510	Strawn	40
Maljamar East, Lea	Apr 40	4340	30	Grayburg-San And	37	AC	SS-Do	M	10	SGD	4874	San Andres	40
Maljamar North; Lea	Jun 39	3880	10	Grayburg	35	NC	SS-Do	P	por	SGD	4097	Grayburg	200
Maljamar South; Lea	Dec 39	4048	10	Grayburg	32	NC	SS-Do	P	por	SGD	4840	Grayburg	80
Maljamar South Yates; Lea	Apr 57	3313	17	Yates		NC	SS	P	por	SGD	4848	Queen	40
Maroon Cliffs Bone Spring; Eddy	May 59	6794	20	Bone Spring	30						7386	Bone Spring	40
Maroon Cliffs Tansill; Eddy	Jun 60	2170	20	Tansill	30						7386	Bone Spring	40
Mason East Delaware; Lea	Dec 61	4443		Delaware	30						4568	Delaware	40
Mason North Delaware; Eddy-Lea	Sep 54	4115	10	Delaware	42	NC	SS	24	25	SGD	4403	Delaware Sd	1640
McCormack; Lea	Nov 47	7148	13	Silurian	43	NF	Do	P	por	WD	8318	Pre-Cambrian	120
McMillan; Eddy	Dec 38	826	5	Queen	29						3303	San Andres	640
	Sep 49	681	8	Seven Rivers		NC	SS	P	por	SGR			
McMillan Seven Rivers; Eddy	Dec 50	380	7	Seven Rivers	34	NC	Do	P	por	SGR	381	Seven Rivers	160
McMillan West Queen; Eddy	Sep 61	1836	13*	Queen	35						1836	San Andres	40
Medicine Rock Devonian; Lea	Jul 61	12740	12*	Devonian	46						12848	Devonian	320
Mesa Queen, Lea	Aug 62	3408	5	Queen	32						3458	Queen	160
Mescalero Devonian; Lea	Oct 52	9806	30	Devonian	44	AC	Do	36	8	WD	10491	Devonian	240
Mescalero Permo-Penn; Lea (Formerly Mescalero Penn)	Mar 52	8390 -10178	18	Permo-Penn	46	AC	Ls	18	8	SGD	11334	Devonian	240
Mescalero San Andres; Lea	May 62	4063	67	San Andres	16						10631	Devonian	80
Mescalero North Bend; Lea	May 56	10180	11	Bend		AC	Ls	P	por	SGD	10777	Devonian	160
Mescalero North Wlfcp; Lea	Jul 60	8350	71	Wolfcamp	43						10800	Devonian	80
Midway Abo; Lea	Oct 62	8661	33	Abo	38						9014	Abo	
Millman, Eddy	Aug 51	1883	6	Grayburg	30	NC	SS-Do	P	por	SGR	2733	San Andres	480
Millman East Queen-Grayburg; Eddy	Apr 58	1700	8	Queen-Grayburg	30	NC	SS	P	por	SGR	3663	San Andres	2600
Millman East San And; Eddy	Jul 59	2413	17	San Andres	38						3663	San Andres	40
Millman East Sev Riv; Eddy	Sep 59	1030		Seven Rivers									880
Milnesand Penn; Roosevelt	Oct 56	9802	8	Penn	46	AC	Ls	P	4	SGR	11907	Granite	520
Milnesand San Andres; Roosevelt	Apr 58	4484	40	San Andres	30	AC	Do	P	8	WD	11907	Granite	1720
Milnesand East Penn; Roosevelt	Sep 58	9262	76	Penn	40	AC	Ls	P	4	SGD	9809	Penn	40
Monument Gas; Lea	Mar 29	3475 -4156		Grayburg-San And							9963	Pre-Cambrian	1440
Monument Abo; Lea	Sep 48	7160	30	L Leonard	41	AC	Do	P	por	SGD	9963	Pre-Cambrian	200
Monument Blinebry; Lea	May 49	5695	30	Yeso	30	AC	Do	M	8	WD	9953	Pre-Cambrian	2120
Monument Ellen; Lea	Aug 54	9780	18	Ellen		AC	Do	P	3	SGD	9953	Pre-Cambrian	640
Monument Grayburg; Lea	Jun 58	3780	20	Grayburg	36						10238	Pre-Cambrian	40
Monument McKee; Lea	Nov 48	9890	40	Simpson	67	AC	SS	M	15	SGD	10235	Pre-Cambrian	800
Monument Paddock; Lea	Jan 48	5180	20	Leonard	40	AC	Do	P	8	SGD	9953	Pre-Cambrian	1440
Monument Tubb; Lea	Jun 50	6456	34	Tubb	38	AC	SS-Do	P	6	SGD	6938	Drinkard	320
Monument Draw; Lea	Apr 62	8226	32*	Devonian	38						10014	Montoya	40
Moore Devonian; Lea	Apr 52	10375	73	Devonian	45	AC	Do	M	4	WD	10946	Devonian	760
Moore Penn; Lea	Aug 52	9654	15	Penn	48	AC	Ls	P	7	SGD	10232	Miss	120
Moore Wolfcamp; Lea	Jul 52	8196	40	Wolfcamp	60	AC	Ls	P	8	SGD	13950	Devonian	160
Nadine; Lea	Feb 50	7363	15	L Leonard	34	E	Do	P	por	SGD	8021	Devonian	120
New Hope; Roosevelt	Jun 51	6131	11	Penn			Ls	P	por	SGD	9067	Pre-Cambrian	40
Nichols; Eddy	Jul 48	2919	18	San Andres			SS-Do	P	9	SGD	3049	San Andres	320
Oil Center Blinebry; Lea	Feb 62	5607	29*	Blinebry	44						12010	Ellen	360
P C A; Eddy	Dec 39	1500	10	Yates	20	AC	Ls	P	por	WD	1956	Yates	480
Paddock; Lea	Apr 45	5170	80	Glorieta	37	NC	Do	4	11	SGD	8370	Pre-Cambrian	3240
Paddock North; Lea	Jun 59	5620		Paddock									40
Paddock South Glorieta; Lea	Jan 58	5164	88	Glorieta	36	NC	Do	P	8	SGD	7100	Drinkard	360
Paduca Delaware; Lea	Sep 60	4670	16	Delaware	41						4803	Delaware	2080
Palmillo; Eddy (Abd 1960, Rev 1961)		1486	10	Seven Rivers			SS	P	por		2561	Grayburg	80
Parallel Delaware; Eddy	Jun 53	7003	30	Delaware Mtn							16459	Pre-Cambrian	80
Parallel Tansill; Eddy	Apr 58	2308	3	Tansill	21	AN	Do	P	por	SGD	7605	Bone Spring	40.
Pearl Bone Spring; Lea	Sep 55	8198	20	Bone Spring	40	AC	Ls	P	por	SGD	13950	Devonian	40
Pearl Penn; Lea	Dec 60	12840	24	Penn	43						14100	Devonian	80
Pearl Queen; Lea	Dec 56	4806 -5024	28	Queen	38	AC	SS	M	12	SGD	13950	Devonian	3880
Pearl Seven Rivers; Lea	Nov 58	4084	13	Seven Rivers	40	AC	SS	M	13	SGD	13950	Devonian	40
Pearl East Queen, Lea	Jun 61	4832	3*	Penrose	36						5357	Grayburg	40
Pearl East Sev Riv; Lea	Jun 58	4048		Seven Rivers									160
Pearl West Queen; Lea	Oct 59	4912	10	Queen Sd	34						13850	Devonian	160
Pearsall; Lea	Jan 40	3320	10	Yates	37	NC	SS	21	23	SGD	4274	San Andres	1200
		3800	10	Queen	37								
Pecos San Andres; Chaves	Nov 61	1128	18	San Andres	36						1170	San Andres	180
Pecos Delaware; Lea (Extended from Texas 1962)				Delaware									40
Penasco San Andres; Eddy	Dec 62	1382	5	San Andres	34						2323	Glorieta	40
Penasco Wolfcamp; Eddy	May 60	5740	18	Wolfcamp	45						6100	Wolfcamp	40
Penrose-Skelly; Lea	Jan 36	3900 -3700	30	Queen-Grayburg	36	AC	SS-Do	P	6	SGD	8370	Pre-Cambrian	9600
Prairie San And; Roosevelt	Mar 59	4858	32	San Andres	33						10000	Penn	40
Prairie East Penn; Roosevelt	Aug 61	9086	4*	Bough C	47						9730	Bough C	120
Prairie South Penn; Roosevelt	Sep 60	9532	10	Penn	47						9800	Penn	720
Premier; Eddy	36	3088	20	Grayburg	36	NC	SS	P	por	SGD	3500	San Andres	3120

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA							OIL AND GAS CONDENSATE PRODUCTION				GAS PRODUCTION			
	1962						CRUDE OIL		CONDENSATE		DRY GAS		CASINGHEAD GAS	
Total oil, gas, gas cond. wells drilled all yrs	Oil, gas, gas cond. wells drld	Wells producing: Flowing	Artif. lift	Gas	Wells abd: Drld dry	Abd.	Bbls in 1962	Cumulative bbls to 1/1/63	Bbls in 1962	Cumulative bbls to 1/1/63	MCF in 1962	Cumulative in MCF to 1/1/63	MCF in 1962	Cumulative in MCF to 1/1/63
3	3	1	2	0			44,013	118,727						
2	0	0	1	0			28,747	396,833						
7	0	4	2	0			108,808	818,381						
4	0	0	0	3							148,334	2,308,277		
1	1	1	0	0			442	8,311						
1	0	0	1	0			31,876	41,800						
1	Comb w/Maljamar 1966							19,730						
-0	Comb w/Maljamar GB-SA Apr 1961							198,154						
3	0	0	1	0			2,308	73,113						
1	Shut In						0	930						
1	Shut In						0	14,946						
1	0	0	1	0			2,100	16,100						
1	0	0	1	1			871	871						
41	1	9	32	0	3		142,390	2,030,836						
3	0	0	3	0			32,557	566,880						
16	0	0	12	0			7,475	231,498						
6	0	0	1	0			46	13,866						
1	0		1	Abd Mar 1962			186	753						
8	7	4	0				343,447	386,516						
4	4	4	0	0	0	0	3,012	3,012						
7	0	6	1	0	0	1	303,473	3,437,006						
6	0	1	5	0	0	0	36,926	648,933						
2	2	0	2	0	1	0	7,811	7,811						
1	0	0	0	1					308	2,130	41,073	107,308		
3	0	0	2	0			16,304	40,000						
12	0	1	7	0			13,648	108,487						
65	2	28	24	0			442,136	1,939,714						
1	Abd 1960;Recomp in Hillman E Queen-Grayburg							4,642						
22	0	1	21	0			76,908	119,113						
13	0	1	2	0	0	3	27,861	901,848						
43	28	21	14	0	1	0	307,883	301,446						
1	Comb w/Milnesand Penn 1966							1,480						
9	See Eunice Gas													
5	Converted to Salt Water Disposal Well 1960							111,000						
62	4	11	20	0			340,000	8,420,856						
1	0	0	0	1					2,136	60,902	215,900	2,790,000		
7	Comb w/Eunice-Monument							9,979,300						
5	2	0	0	2			0	13,074	60,307	183,016	1,817,390	7,420,815		
36	2	10	11	0			411,720	4,371,512						
9	6	2	2	0			77,150	146,797						
1	1	0	1	0			1,196	1,196						
19	0	13	5	0			890,967	10,558,100						
3	Abd 1962						0	20,225						
2	0	0	0	2					542	73,061	83,900	2,283,426		
3	0	0	3	0			6,048	143,000						
1	Abd 1963						0	6,065						
12	Comb w/Artesia 1965							183,106						
9	9	9	0	0	0	0	43,081	43,081						
12	0	0	5	0			10,090	701,429						
131	5	63	60	0			509,271	13,996,682						
1	0	0	1	0			640	3,710(Shut In Aug 1962)						
9	3	3	6	0			90,427	323,904						
66	4	34	31	0	1		704,817	1,891,436						
2	0	0	1	0			1,028	2,061						
2	1	0	2	0			6,167	60,390						
1	0	0	1	0			520	4,221						
1	Abd Dec 1966;Recomp in Pearl Queen						0	4,238						
1	0	1	0	0			5,308	30,058						
147	18	5	142	0	6		1,804,337	3,878,283						
1	0	0	0	0			0	2,088						
1	0	1	0	0			668	1,111						
1	0	0	0	1							102,878	411,837		
4	0	0	4	0			90,000	108,194						
30	0	1	20	0			84,792	1,341,083						
3	1	0	1	0	1	0	441	441						
7	2	0	2	0	1		8,268	8,268						
1	1	1	0	0			431	431						
1	0	0	1	0			1,200	7,030						
340	12	86	96	0			336,728	13,482,837						
1	Abd Jan 1960						0	111						
3	3 Comb w/Prairie F Penn Jul 1962							10,113						
18	3	14	2	0	2		817,300	1,843,987						
78	Comb w/Grayburg Jackson 1967							3,306,000						

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TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD, COUNTY	DISCOVERY MO - YR	GEOLOGY — PRODUCING FORMATIONS: AVG TOP FT	AVG THK *AVG PERFS IN FT	GEOLOGICAL FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Quahada Ridge Delaware;Eddy	May 54	6112	6	Delaware Mtn							15654	Fusselman	40
Quail Ridge Bone Spring,Lea	Oct 61	10118	16*	Bone Spring	39						13972	Miss	80
Quail Ridge Morrow; Lea	Oct 61	13325	12*	Morrow	57						13972	Miss	1280
Quail Ridge North Morrow, Lea	Apr 61	13160	37	Morrow							14784	Devonian	640
Querecho Plains Bone Spring, Lea	Nov 58	11922	13	Penn	49						14330	Devonian	40
Querecho Plains Delaware, Lea	Mar 59	6860	11	Delaware Sd	37						9393	Bone Spring	40
Querecho Plains Penn, Lea	Jan 57	11593	50	Penn	42		Lm	P	por	SGD	14217	Devonian	40
Querecho Plains Queen; Lea	Mar 61	3940	21*	Queen							7160	Bone Spring	40
Ranger Lake Penn; Lea	Sep 56	10312	33	Penn	41	AC	Lm	P	8	SGD	12977	Devonian	960
Red Hills; Eddy	Feb 56	1630	44	Yates	29		SS	M	15	SGD	1832	Yates	200
Red Lake, Eddy	Oct 24	1725		Grayburg	29	MC	SS-Do	2	110	SGD	12431	Ellen	8160
		2100		San Andres									
Red Lake Penn, Eddy	Apr 56	9443	22	Penn		MC	Lm	P	por	SGD	10404	Devonian	960
Red Lake Seven Rivers; Eddy	Apr 52	673	54	Seven Rivers		MC	SS	M	12	SGD	727	Seven Rivers	40
Red Lake East Queen; Eddy	Mar 59	1560	7	Queen	36						2230	San Andres	920
Red Lake North Queen; Eddy	Nov 58	1472	41	Queen-Grayburg	38	MC	SS	M	15	SGD	2087	San Andres	240
Reeves Bone Spring; Lea	Sep 54	9980	6	Bone Spring			SS	P	por	SGD	12355	Devonian	40
Reeves Devonian; Lea	Feb 60	12180	10	Devonian	44						12341	Devonian	240
Reeves Penn; Lea	Nov 56	10945	10	Penn	41	AC	Lm	P	por	SGD	12341	Devonian	200
Remuda Wolfcamp; Eddy	Dec 60	11111	43	Wolfcamp	47						15144	Devonian	80
Rhodes; Lea	Jan 29	3000	25	Yates-Sev Riv	36	MC	SS-Do	M	15	SGD	4110	San Andres	2320
Rhodes Gas; Lea	Sep 57	3000		Yates		MC	SS	M	15	SGD	3300	Seven Rivers	160
Roberts, Lea	Sep 43	4195	15	Grayburg	34	AC	SS	9	11	SGD	4660	San Andres	4040
Roberts West; Lea	Dec 45	4192	13	Grayburg	34	AC	SS	P	11	SGD	4660	San Andres	
Robinson; Eddy-Lea	26	3550	20	Grayburg	34	MC	SS	P	por	SGD	4483	San Andres	2920
		3919	30	San Andres									
Robinson North Queen; Eddy	Jan 61	3628	46*	Queen	36						4218	Lovington Sd	40
Round Tank San And; Chaves	Apr 62	2960	20*	San Andres	34						10590	Devonian	520
Russell; Eddy	Apr 42	783	10	Yates	38	AM	SS-Do	30	19	SGD	2300	Devonian	2480
S R R Devonian; Lea	May 55	11103	50	Devonian	40						11360	Devonian	120
S R R Penn; Lea	Nov 55	9208	10	Penn	48						11360	Devonian	80
Saladar Yates; Eddy	Mar 56	650	20	Yates	34		SS	M	15	SGD	816	Yates	320
Salado Draw; Lea	Feb 62	5005	4*	Delaware							5300	Delaware	440
Salt Lake; Lea (Abd Dec 48, Rev Jul 62)	Jul 41	2990	10	Yates-Sev Riv			SS	P	por	SGD	4003	Seven Rivers	440
Salt Lake South Morrow; Lea	Apr 60	13240	39	Morrow	53						16600	Granite	160
Salt Lake South Penn; Lea	Jan 58	12909	7	Penn	47		Lm	P	7	SGD	16600	Granite	160
San Miguel Yates-Seven Rivers; Lea	Aug 59	3613	17	Seven Rivers	31						3630	Seven Rivers	40
San Simon; Lea	Nov 43	3935	20	Yates	34	AC	SS	5	20	SGD	4183	Yates	80*
San Simon North Yates; Lea	Sep 57	3800		Yates									640
Sand Hills; Lea	Apr 32	4292	10	Grayburg			SS	P	por		8722	Montoya	40
Sand Springs Devonian; Lea (Abd 1960, Rev Apr 62)	Nov 57	13115	38	Devonian		AC	Do	P	5	WD	13204	Devonian	80
Sanmal Penn; Lea	Oct 57	11708	14	Penn		MC	Lm	P	por	SGD	11842	Penn	80
Sanmal San Andres; Lea	Jul 55	4571	10	San Andres	38	MC	SS	P	por	SGD	4711	San Andres	80
Santo Nino; Eddy	Jan 51	3960	10	Delaware Mtn			SS	[illegible]	24	SGD	4351	Delaware Mtn	120
Saunders; Lea	Jan 50	8831	50	Wolfcamp	42	AC	Lm	P	7	SGD	14809	Pre-Cambrian	4880
	May 60	9934	26	Penn									
Saunders East Permo-Penn; Lea	Mar 62	10363	65	Penn	42						12521	Penn	160
Saunders North; Lea	Jan 51	9775	30	Permo-Penn	42	AC	Lm	P	7	SGD			
Saunders South; Lea	Apr 51	10587	20	Penn	36		Lm	P	8	SGD	10621	Penn	240
Sawyer Devonian; Lea	Aug 55	11618	50	Devonian	42	AC/T	Do	P	5	WD	12097	Devonian	80
Sawyer San Andres; Lea	Feb 47	4926	25	San Andres	25	MC	Do	2	10	[illegible]	12097	Devonian	1040
Sawyer South San And; Lea	Jan 58	4950	28	San Andres	28	AC	Do	6	8	SGD	5032	San Andres	80
Scanlon Draw Queen; Eddy	Apr 61	1983	2*	Queen	34						2100	Penrose	40
Scharb, Lea	Jan 60	13033	23	Atoka	54						14647	Devonian	160
Scharb Bone Spring; Lea	Jan 62	10152	14*	Bone Spring	38						14647	Devonian	160
Seven Rivers; Lea	Dec 34												
Shoe Bar Devonian; Lea	Sep 53	12482	76	Devonian	57	AC	Do	P	6	WD	12780	Devonian	200
Shoe Bar Dev North; Lea	Dec 56	12638	100	Devonian	60	AC	Do	P	6	WD	12978	Devonian	80
Shoe Bar Penn; Lea	Mar 54	10440	53	Penn	56	MC	Lm	P	por	SGD	12978	Devonian	120
Shoe Bar Penn Gas; Lea	Feb 54	12310	20	Bend		MC	Lm	P	por	SGD	12978	Devonian	320
Shoe Bar North Penn; Lea	Aug 56	10934	26	Penn	43	MC	[illegible]	P	por	SGD	12978	Devonian	40
Shugart; Eddy	Jul 37	2600	15	Yates	38	MC	SS	P	por	SGD	13446	Montoya	8000
		3450	10	Queen									
Shugart Bone Spring; Eddy	Apr 61	8135	50*	Bone Spring	41						12858	Devonian	80
Shugart Delaware; Eddy	Dec 58	4970	24	Delaware Sd	38	None	SS	M	24	SGD	13446	Montoya	80
Shugart Penn, Eddy	Jan 58	10912	49	Penn	60	MC	Lm	P	por	SGD	13446	Montoya	160
Shugart Sil-Dev, Eddy	Feb 57	12362	70	Siluro-Devonian		AC	Do	M	6	WD	13446	Montoya	960
Shugart Wolfcamp, Eddy	Mar 61	9615	10*	Wolfcamp	41						13446	Montoya	40
Shugart North; Eddy	38	3350		Queen	33	ML	SS	P	por	SGD	4890	San Andres	4600
		3937	31	Grayburg		ML	SS	P	por	SGD			
	Aug 60	2620	12	Yates									
Shugart North Grayburg;Eddy	Jan 56	3957	31	Grayburg	32						4785	Delaware Sd	200
Skaggs, Lea	Mar 37	3800	50	Grayburg	36	AM	SS-Do	7	3	SGD	9475	Ellen	3400
Skaggs Drinkard, Lea	Sep 53	6856	30	Leonard	37	AM	Do	P	por	SGD	9671	Simpson	360
Skaggs Glorieta, Lea	Jun 58	5266	36	Glorieta	33	AM		M	por	SGD	9871	McKee	360
Skaggs North Drinkard; Lea	Feb 60	6898	30	Drinkard							9871	McKee	320
Sombrero Penn; Lea	Feb 57	13166	22	Penn							13700	Miss	320
Spencer Devonian; Lea	May 56	11034	12	Devonian		AC	Do	P	4	WD	11046	Devonian	40
Square Lake; Eddy	Nov 41	2700	15	Grayburg	38	MC	SS	110	21	SGD	6587	Abo	14280
Square Lake North Grayburg, Eddy	Nov 59	3833	33	Premier Grayburg	34						13400	Devonian	1520
Squyres Devonian; Roosevelt	Jan 54	9229	40	Devonian	45	AC/T	Do	200	8	WD	9637	Devonian	40
Squyres Penn; Roosevelt	Apr 61	8380	10*	[illegible]	45						9637	Devonian	40

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA							OIL AND GAS CONDENSATE PRODUCTION				GAS PRODUCTION			
	1962						CRUDE OIL		CONDENSATE		DRY GAS		CASINGHEAD GAS	
TOTAL OIL, GAS, GAS COND WELLS DRILLED ALL YRS	OIL, GAS, GAS COND WELLS DRLD	WELLS PRODUCING FLOWING	WELLS PRODUCING ARTIF LIFT	WELLS PRODUCING GAS	WELLS ABD DRLD DRY	WELLS ABD PROD UCERS	BBLS IN 1962	CUMULATIVE BBLS TO 1/1/63	BBLS IN 1962	CUMULATIVE BBLS TO 1/1/63	MCF IN 1962	CUMULATIVE IN MCF TO 1/1/63	MCF IN 1962	CUMULATIVE IN MCF TO 1/1/63
1	0	0	1	0			1,343	18,578						
2	1	2	0	0	2		73,871	73,871						
2	2	0	0	2					4,610	4,610	109,082	109,082		
1	0	0	0	1					1,173	1,173	106	106		
1	0	0	1	0			3,947	17,313						
1	0	0	1	0			575	9,599						
1	0	0	1	0			27,046	286,851						
1	Abd Dec 1961													
24	0	7	16	0	0	0	380,174	2,828,488						
5	0	0	1	0	1	1	196	25,100						
304	8	12	136	0	4		250,358	4,033,120						
3	0	0	0	3					2,954	18,985	1,151,857	5,785,577		
1	0	0	0	0			0	530						
23	2	14	9	0			59,906	179,380						
6	1	6	0	0			6,705	47,338						
1	Abd 1954						0	1,010						
3	1	2	1	0	1		122,164	249,238						
5	0	3	0	0			83,788	685,050						
1	0	1	0	0			2,186	7,741						
36	1	21	17	0			231,279	5,740,745						
1	Comb w/Jalmat 1957										0	23,092		
101	Comb w/Jaljamar GB-SA 1961							2,164,368						
	Comb w/Roberts 1947													
73	2	27	46	0			161,626	1,583,690						
1	0	0	1	0			2,072	2,794						
13	13	0	13	0	0		4,155	4,155						
62	0	0	15	0			88,528	1,829,673						
3	0	0	1	0			24,532	414,420						
2	Abd 1959						0	46,938						
6	2	0	6	0	1		9,767	78,463						
11	11	7	4		1		32,833	32,833						
11	1	0	1	0			4,690	299,838						
1	0	0	0	1					7,521	8,545	387,600	434,337		
1	0	0	0	1					10,251	34,703	306,715	1,202,120		
1	0	0	1	0			11,436	37,874						
2	0	0	2	0			2,106	97,463*						
21	0	13	6				29,765	196,892						
1	Abd Jan 1953						0	807						
2	1	0	1	0			11,601	27,621						
1	0	0	0	0			0	10,433						
2	0	0	2	0			3,994	63,424						
3	Abd 1956						0	9,705						
114	3	8	97	0			1,417,591	21,740,270						
3	3	3	0	0	0		78,384	78,384						
	Comb w/Saunders 1961													
		0	1	0			8,922	129,618						
1	0	0	0	0			0	177,280						
26	1	0	0	10			0	62,828	11,383	37,339	1,044,636	1,633,437		
2	Comb w/Sawyer San Andres Nov 1959							16,321						
1	0	0	0	0			0	80						
1	Abd Jan 1962								0	2,155	0	4,520		
1	1	1	0	0			35,256	35,256						
	Comb w/E-K Queen													
5	0	0	2	0			12,880	940,766						
2	0	0	1	0			4,588	139,509						
3	0	2	1	0			70,243	120,230						
1	0	0	0	0					0	14,084	0	806,135		
1	0	1	0	0			1,217	25,322						
200	23	25	175	0	7		745,458	2,916,231						
1	0	1	0	0			34,600	39,317						
2	0	1	1	0			28,890	80,338						
2	0	0	0	1					15,509	157,397	575,227	4,874,742		
2	0	0	0	1					95,837	537,854	1,646,196	9,747,610		
1	0	1	0	0			2,088	2,196						
115	Abd Nov 1961						0	2,309,301						
6	Comb w/Shugart N 1959							22,074						
85	0	29	41	0			100,704	5,471,072						
9	3	5	4	0	1		50,139	352,801						
9	4	1	7	0	3		74,314	218,349						
2	1	0	0	2					8,896	23,396	508,217	1,343,721		
2	0	0	0	2					11,370	26,110	237,030	386,476		
1	Abd 1956						0	1,634						
357	11	61	200	0	2		633,863	10,523,169						
38	11	15	13	0	4		330,987	406,038						
1	Abd Jan 1962						0	7,887						
1	0	0	1	0			1,277	2,333						

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD; COUNTY	DISCOVERY MO.-YR.	GEOLOGY: PRODUCING FORMATIONS: AVG. TOP FT.	AVG. THK. *AVG. PERFS IN FT.	GEOLOGICAL FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
T V Morrow; Chaves	Apr 60	12880	40	Morrow	56						11000	Morrow	160
Tatum Wolfcamp; Lea	Oct 57	10285	31	Wolfcamp	43	AC	Lm	6	7	SGD	14303	Devonian	120
Teague; Lea	Mar 48	9340	50	Simpson	41	AC	SS	M	por	SGD	10218	Pre-Cambrian	640
Teague Abo; Lea	Sep 59	6784		Abo									320
Teague Devonian; Lea	Feb 52	7150	25	Devonian	41	AC	Do	P	por	SGD	10165	Pre-Cambrian	200
Teague Ellen; Lea	Feb 50	9700	50	Ellen	45	AC	Do	M	3	WD	10165	Pre-Cambrian	400
Teague Grayburg; Lea	May 37	3685	4	Grayburg	34	AC	SS-Do	P	10	SGD	10165	Pre-Cambrian	80
Teas; Lea	Mar 61	3385	5	Yates	34	AC	SS	P	por	SGD	3790	Seven Rivers	930
		3332	5	Seven Rivers									
Teas Bone Spring; Lea	Dec 62	9408	31	Bone Spring	38						14948	Devonian	40
Teas Morrow; Lea	Dec 62	13294	38	Morrow							14948	Devonian	640
Teas West Yates; Lea	Dec 58	3230	12	Yates	30						3323	Yates	280
Tecolote Peak Dela; Eddy	Mar 50	2512	3	Delaware Sd	41						2514	Delaware	40
Terry Blinebry; Lea	Mar 52	5840	20	Yeso	42	AC	Do			SGD	9150	Pre-Cambrian	4260
Tonto; Lea	Jun 44	3565	8	Seven Rivers	35	MC	Do			WD	3648	Seven Rivers	120
Tonto Wolfcamp; Lea	Apr 63	11160	20*	Wolfcamp	40						13800	Miss	40
Tonto Deep; Lea	Jun 59	11394	29	Wolfcamp	44						14923	Devonian	80
Tonto South Yates; Lea	Jun 61	3001	21	Yates							3192	Seven Rivers	120
Tonto West Atoka; Lea	Apr 60	13325	53	Atoka	53						14943	Devonian	160
Tonto West Yates; Lea	May 60	3259	4	Yates	30						14948	Devonian	240
Townsend Penn; Lea	Jun 56	11040	40	Penn	41	AC	Lm	P	7	SGD			40
Townsend Wolfcamp; Lea	May 52	10410	39	Wolfcamp	40	MC	Lm	38	8	SGD	13803	Devonian	4800
Tristie Draw; Lea	Feb 61	5062	4*	Delaware Sd	40						5200	Delaware	400
Tubb Oil; Lea	May 56	6185	72	Tubb	38	MC	Do	S	19	SGD	8370	Pre-Cambrian	800
Tubb Gas; Lea	Sep 46	6090	30	Yeso		MC	Do	P	19	SGD	8370	Pre-Cambrian	14480
Tulk Wolfcamp; Lea	Aug 51	9700	23	Wolfcamp	41	AM	Lm	P	8	SGD	13100	Penn	480
Tulk North Wolfcamp; Lea	Feb 58	9864	34	Wolfcamp	41	AM	Lm	P	por	SGD	10294	Penn	40
Tulk South Wolfcamp; Lea	Jan 62	9682	14*	Wolfcamp	40						11179	Penn	40
Turkey Track; Eddy	Aug 45	3030	10	Queen	38	Terr	SS	P	por	SGD	3094	Grayburg	1800
		2575	15	Grayburg									
Turkey Track Sev Riv; Eddy	Jul 48	1686	10	Seven Rivers	34	Terr	SS	P	por	SGD	3096	Delaware Mtn	320
Turkey Track East; Eddy	Apr 50	2238	9	Queen	34	Terr	SS	P	por	SGD	4371	Delaware	360
Turkey Track West; Eddy	May 51	2747	5	San Andres		Terr	Do	P	por	SGD	3005	San Andres	80
Twin Lakes Devonian; Chaves	Dec 60	7283	6	Siluro-Devonian	54	AC	Do	P	por	WD	8932	Devonian	40
U S Delaware; Eddy	Sep 53	6890	30	Delaware Mtn							13611	Simpson	40
Vacuum Abo, Lea	Oct 60	8630	70	Abo	40						13611	Devonian	3360
Vacuum Devonian; Lea	Oct 62	13069	28*	Devonian	48						13611	Devonian	40
Vacuum Drinkard; Lea	Dec 61	8420	28*	Drinkard	41						13611	Devonian	120
Vacuum Graybg-San And; Lea	May 29	4313	20	Grayburg	38	AC	Do	400	9	SGD WD	13611	Devonian	21730
		4650	75	San Andres									
Vacuum Queen Oil; Lea	May 61	3933	5*	Queen	38						13611	Devonian	680
Vacuum Queen Gas; Lea	Mar 57	3890	38	Queen		AC	SS	P	por	SGD	13611	Devonian	160
Vacuum Wolfcamp; Lea	Oct 62	9818	130	Wolfcamp	41						13611	Devonian	40
Vacuum Yates; Lea	Jun 57	3067	14	Yates	33	AC	SS	100	11	SGD	13611	Devonian	320
Vacuum Yeso; Lea	Oct 62	6394	38	Yeso	36						13611	Devonian	120
Vacuum East Abo; Lea	Jan 61	8690	40*	Abo Reef	39						9075	Abo Reef	240
Vacuum South Bone Spr; Lea	Apr 58	8504	10	Bone Spring	34		SS	M	por	SGD	13000	McKee	120
Vacuum South Devonian; Lea	Jan 58	11643	27	Devonian	46	AC	Do	226	7	WD	11648	Silurian	480
Vacuum South Wolfcamp; Lea	May 60	10011	16	Wolfcamp							11675	Devonian	40
Vandagriff-Keyes; Eddy		1374	10	Queen			SS	M	15	SGD	2303	Grayburg	4480
Wantz Abo; Lea	Jan 52	7218	20	L Leonard	41	AC	Do	P	14	SGD	9308	Montoya	1640
Warren Abo; Lea	Oct 54	7220	45	Abo	40	AC	Do	P	5	SGD	9852	Pre-Cambrian	180
Warren Blinebry; Lea	Jan 57	5738		Blinebry	38								320
Warren Connell; Lea	Dec 58	9248		Connell									160
Warren Drinkard; Lea	Mar 50	6768	15	Yeso	53	AC	Do	P	por	SGD	9392	Pre-Cambrian	160
Warren McKee; Lea	Dec 48	8865	50	Simpson	46	AC	SS	40	13	SGD	9852	Pre-Cambrian	1040
Warren Tubb; Lea	Jan 37	6300		Tubb									720
Warren North McKee; Lea	Jan 52	9012	100	Simpson	48	AC	SS	40	13	SGD	9475	Ellen	1040
Watkins; Lea	Dec 45	3364	10	Seven Rivers	28	MC	SS-[illegible]	P	por	SGD	4364	Grayburg	240
Watkins Grayburg; Lea	Jan 48	4317	15	Grayburg	27	MC	SS	P	por	SGD	4368	Grayburg	40
Weir; Lea	May 46	6700	80	Leonard	38	AC	Do	P	por	SGD	10463	Pre-Cambrian	160
	Apr 50	6384		Tubb	37								
Weir Blinebry; Lea	May 61	5782		Blinebry-Paddock									120
Weir Tubb Gas; Lea	Apr 59	6474		Tubb									160
Weir East; Lea	Mar 62	5814	16	Blinebry	43								40
Welch Delaware; Eddy	Nov 57	2082	6	Delaware	41		SS	M	24	SGD	12620	Atoka	160
Welch Penn; Eddy	Oct 56	12302	28	Atoka			Lm	P	8	SGD	12620	Atoka	320
White City Penn; Eddy	Apr 60	9806	10	Wolfcamp	58						12212	Devonian	640
White Ranch Sil-Dev; Chaves	Apr 53	8727	36	Silurian-Devonian	47	AC	Do	150	8	WD	8810	Devonian	120
White Ranch West Dev;Chaves	Jul 59	8132	13	Devonian	46						8360	Devonian	40
Williams Penn; Lea (Abd 1960 Rev Mar 62)	Jan 55	11087	6	Bend	48	ML	SS	P	por	SGD	12519	Devonian	40
Wilson; Lea	Aug 39	3600 -3850	38	Yates-Sev Riv	31	ML	SS-Do	P	15	SGD	4695	San Andres	2600
Wilson North; Lea	Feb 51	3980	20	Seven Rivers	32	ML	SS-Do	P	15	SGD	4201	Seven Rivers	80
Wilson West; Lea	Nov 48	3936	10	Seven Rivers	27	ML	SS-Do	P	15	WD	3948	Seven Rivers	400
Windmill San Andres; Chaves	Feb 59	2514	18	San Andres	31						2750	San Andres	40
Wye Delaware; Eddy	Sep 56	5180	76	Delaware Sd			SS	M	24	SGD	7300	Bone Spring	40
Young; Lea	Feb 45	3765	10	Queen	37	None	SS	P	por	SGD	4677	Grayburg	1120
Young San Andres; Lea	Jun 36	4048	27	San Andres	36	None	SS	P	por	SGD	4648	San Andres	130
Not Named; Lea	Jun 61	5113	18	Grayburg	35						5131	Grayburg	120
Not Named, Lea	Jul 62	5662	96	Paddock							5780	Paddock	
Not Named; Eddy	Mar 61	9346	88*	Morrow							9600	Morrow	160
Not Named; Eddy	Feb 62	1834	9*	Seven Rivers							2095	Queen	
Not Named; Lea	Sep 62	9445	13*	Canyon	40						9980	Penn	
Not Named, Lea	Jan 62	4962	8*	Penrose	36						5028	Penrose	
Not Named, Lea	Oct 62	3382	10*	Queen							3421	Queen	
Not Named; Lea	Jul 62	11410	20*	Strawn	47						12834	Morrow	
Not Named; Lea	Jul 62	12440	30	Morrow							12834	Morrow	
Not Named; Roosevelt	May 61	9451	4*	Bough C	46						9470	Bough C	40

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA: Total oil, gas, gas cond wells drilled all yrs	1962: Oil, gas, gas cond wells drld	Wells producing: Flowing	Wells producing: Artif lift	Wells producing: Gas	Wells abd: Drld dry	Wells abd: Abd producers	OIL AND GAS CONDENSATE PRODUCTION: Crude oil, bbls in 1962	Crude oil, cumulative bbls to 1/1/63	Condensate, bbls in 1962	Condensate, cumulative bbls to 1/1/63	GAS PRODUCTION: Dry gas, MCF in 1962	Dry gas, cumulative in MCF to 1/1/63	Casinghead gas, MCF in 1962	Casinghead gas, cumulative in MCF to 1/1/63
1	0	0	0	1					38,650	31,340	487,904	480,632		
3	0	1	2	0			31,818	349,011						
16	0	0	10	0			48,265	2,026,695						
2	1	0	0	2					469	9,318	112,169	444,369		
5	0	0	3	0	0	2	18,622	391,437						
10	0	0	6	0	0	0	35,636	2,173,303						
2	0	1	0	0	0	0	571	20,090						
23	0	0	21	0			72,527	839,765						
1	1	1	0	0	0	0								
1	1	0	0	1	0	0								
7	0	0	7	0	1	0	69,627	173,593						
1	0	0	0	0			0	2,862						
109	1	74	30	0			587,183	5,444,247						
3	Abd Feb 1962						111	225,412						
1	1	1	Abd Aug 1962				6,108	6,108						
1	0	SI	0	0			0	726						
3	2	1	0	0	1		29,263	34,110						
1	0	0	0	1					3,434	3,434	159,116	159,116		
6	0	3	2	0			84,063	106,868						
1	Comb w/Townsend Wolfcamp													
106	0	18	63	0			480,880	14,512,794						
18	0	2	4	0	2		83,582	116,228						
24	1	21	3	0	1		110,258	817,416						
153	0	0	0	154					204,863	3,232,898	13,728,415	130,177,257		
12	0	0	7	0			35,076	1,343,637						
1	Abd Dec 1962						0	4,679						
1	1	1	0	0	0		14,190	14,190						
48	2	15	27	0	3		91,904	705,845						
8	0	0	8	0			3,084	150,116						
9	3	3	7	0	6		20,394	114,336						
2	Abd Jun 1954						0	728						
1	0	0	1	0			4,769	43,919						
1	0	0	1	0			833	20,386						
84	42	78	6	0	2		2,433,406	3,018,314						
1	1	1	0	0	0	0	2,039	2,039						
3	2	2	1	0			4,981	4,981						
543	7	74	419	0	2		3,341,949	96,067,229						
17	11	12	2	0	1		117,604	129,212						
1	0	0	0	1					636	8,843	27,934	881,796		
1	1	1	0	0	0	0	994	994						
8	0	6	2	0	0	0	14,700	146,813						
3	3	3	0	0	1		2,834	2,834						
6	Comb w/Vacuum Abo 1962						20,707	140,437						
3	0	1	2	0			11,200	103,301						
13	0	0	0	0	0	0	814,357	3,036,325						
1	0	0	1	0			16,070	39,833						
14	0	0	0	12	0	2			104	1,739	617,280	2,909,061		
41	3	16	18	0			213,683	2,014,298						
4	0	0	0	0			1,158	67,623						
2	0	0	0	2					1,415	71,700	121,337	1,6[illegible],706		
1	0	0	0	1							11,085	50,929		
3	0	2	1	0			14,990	220,682						
46	0	11	32	0			838,958	9,139,819						
8	0	0	0	4					NR		798,337	2,430,730		
20	Comb w/Warren McKee 1957							5,606,528						
6	0	0	3	0			1,361	72,436						
1	0	0	1	0			4,434	91,964						
4	0	0	1	0			15,640	175,807						
3	2	3	0	0	0	0	36,940	40,348						
1	0	0	0	1					44,392	119,176	362,229	1,312,044		
1	1	1	0	0	0	0	7,666	7,666						
4	0	0	4	0			8,412	97,237						
1	0	0	0	1							5,042	741,721		
2	0	0	0	2					619	757	185,949	337,100		
3	0	0	3	0			21,004	564,800						
1	0	0	1	0			34,838	136,890						
1	0	0	1	0			838	56,100						
65	0	0	40	0			119,963	8,182,571						
2	0	0	1	0			990	33,813						
18	0	0	6	0			22,293	725,828						
1	Abd Jan 1962						0	0						
1			SI											
28	0	4	21	0			45,752	1,144,942						
2	0	1	2	0			3,998	80,627						
3	0	0	0	0										
1	1													
1	0	0	0	SI										
1	1	0												
1	1													
1	1													
1	1													
1	1													
1	1													
1	0	SI	0	0										

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD; COUNTY	DISCOVERY MO. - YR.	GEOLOGY: PRODUCING FORMATIONS: AVG TOP FT	AVG. THK *AVG PERFS IN FT	GEOLOGICAL FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Not Named; Lea	Aug 61	3326	52	Yates	36						3527	Seven Rivers	40
Not Named; Eddy	Jun 59	8998	112	Bend							9283	Bend	160
Not Named; Eddy	Aug 61	9622	10*	Penn							11560	Miss	160
Not Named, Lea	Oct 61	10001	113*	Wolfcamp	39						12509	Devonian	40
Not Named; Eddy	Jul 61	10096		Morrow	40						10784	Miss	160
Not Named, Eddy	Jul 57	1568	16	Grayburg							1628	Grayburg	160
Not Named, Eddy	Dec 61	2871	29*	Yeso	37						5620	Abo Reef	40
Not Named, Eddy	Apr 61	11213	65*	Morrow							12292	Devonian	160
Not Named, Lea	Nov 61	11050	10*	Bend	46						12497	Devonian	40
Not Named, Chaves	Jun 57	1312	10	Queen							2743	San Andres	160
Not Named; Lea	Sep 36	4148	30	Penrose							4178	Penrose	40
Not Named, Lea	Dec 52	3400		Yates							4000	Yates	160
Not Named; Chaves	Nov 59	1177	8	Queen	35						1190	Penrose	40
Not Named, Lea	Nov 38	2100		Yates							3300	Yates	160
Not Named, Eddy	Apr 62	8616	52*	Bone Spring	41						12794	Miss	
Not Named, Eddy	Apr 62	10212	14*	Wolfcamp	41						12794	Miss	
Not Named, Eddy	Apr 62	11136	24*	Strawn	44						12794	Miss	
Not Named, Lea	Nov 62	10834	29*	Wolfcamp	41						11713	Strawn	
Not Named; Lea	Oct 62	13004	6*	Morrow Sd							13160	Miss	
Not Named; Lea	Nov 61	13238	38*	Morrow							13723	Barnett	160
Not Named, Eddy	Jun 59	9442	16	Penn							10486	Ellen	160
Not Named; Lea	Oct 58	13620	200	McKee	36						13919	Granite	160
Not Named; Eddy	Mar 55	5722	12	Delaware Mtn							16459	Pre-Cambrian	40
Not Named; Lea	Oct 62	9637	17*	Canyon							11400	Miss	
Not Named; Lea	Aug 59	4936	22	San Andres	37						5000	San Andres	160
Not Named, Eddy	Dec 62	8817	6*	Atoka							9608	Morrow	
Not Named; Eddy	Oct 60	7452	15	Atoka							10237	Ellen	320
Not Named; Eddy	Jan 58	3873	5	Delaware Sd							3878	Delaware Sd	160
Not Named; Eddy	Aug 62	1637		L Seven Rivers	38						2693	San Andres	
Not Named; Eddy	Sep 58	1117	30	Grayburg	36						1196	Grayburg	40
Not Named; Chaves	Mar 61	3128	6*	Premier	33						3337	Premier	40
Not Named; Eddy	Oct 60	8685	12	Wolfcamp	40						12160	Devonian	80
Not Named; Chaves	Oct 60	890	20	San Andres	29						930	San Andres	40
Not Named; Lea	Oct 59	4948	35	San Andres	34						5043	San Andres	40
Not Named; Lea	Dec 59	3921	18	Yates	32						4108	Yates	40
Not Named; Eddy	Jan 62	7060	96	Penn							9310	Devonian	
Not Named; Lea	Feb 51	3852		Yates							3860	Yates	160
Not Named; Lea	Sep 58	3788		Yates							3860	Yates	160
Not Named; Lea	Dec 59	3910	10	Yates	35						4111	Yates	40

(a) 12 wells transferred to Anderson Ranch North Wolfcamp 1962

* Corrected

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA 1962: Total oil, gas, gas cond wells drilled all yrs	Oil, gas, gas cond wells drld	Wells producing: Flowing	Wells producing: Artif lift	Wells producing: Gas	Wells abd: Drld dry	Wells abd: Abd producers	Oil and gas condensate production: Crude oil: Bbls in 1962	Crude oil: Cumulative bbls to 1/1/63	Condensate: Bbls in 1962	Condensate: Cumulative bbls to 1/1/63	Gas production: Dry gas: MCF in 1962	Dry gas: Cumulative in MCF to 1 1 63	Casinghead gas: MCF in 1962	Casinghead gas: Cumulative in MCF to 1 1 63
1	Comb w/Teas-Yates 1962													
1	0	0	0	SI										
1	0	0	0	SI										
1	0	0	0	0										
1	0	0	0	SI										
1	0	0	0	SI										
1	0	0	0	0										
1	Abd Aug 1961													
1	0	0	0	0										
1	0	0	0	SI										
1	0	0	0	0			0	9,465						
1	0	0	0	SI										
1	0	0	0	0										
1	0	0	0	SI										
1	1													
1	1													
1	1													
1	1													
1	1													
1	0	0	0	1										
1	0	0	0	SI										
1	0	0	0	SI							0	38,609		
1	0	0	0	0			0	44,788						
1	1													
1	Comb w/Sawyer-San Andres													
1	1	0	0	SI										
1	0	0	0	SI										
1	0	0	0	SI										
1	1													
1	0	0	0	0										
1		0	0	0										
1	0	0	0	0			0	2,865						
1	0	0	0	0										
1	0	0	0	0			0	1,303						
1	0	0	0	0			0	2,073						
1	1	0	0	SI										
1		0	0	1							NR			
1	0	SI	0				0	2,219						
1	0	0	0	0			0	303						

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TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD, COUNTY	DISCOVERY MO - YR	GEOLOGY: [illegible]: AVG. TOP FT	AVG. THK. *AVG. PERFS IN FT	[illegible] FORMATION	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Allison, San Juan	Aug 52	5554	330	Mesaverde							3904	Mesaverde	640
Aleup; Rio Arriba	Feb 52	4135	200	Pictured Cliffs							4355	Pic Cliffs	160
Angel's Peak Dakota; San Juan	Nov 47	6470	60	Dakota	56	ML	SS	2	12	SGD	8043	Entrada	160
Angel's Peak Gallup; San Juan	Feb 58	5013		Gallup							7102	[illegible]	640
Aztec Farmington; San Juan	Aug 53	1491	18	Farmington Ss	58	ML	SS	3	12	SGD	1766	Pic Cliffs	160
Aztec Fruitland; San Juan	Jan 54	1464	26	Fruitland	55	ML	SS	5	16	SGD	1647	Fruitland	5280
Aztec Fruitland North; San Juan	Apr 54	2480	20	Fruitland	58	ML	SS	5	16	SGD			
Aztec Pic Cliffs; San Juan	Jul 51	2650	90	Pictured Cliffs	55	ML	SS	10	20	SGD	3010	Pic Cliffs	60800
Ballard Gallup; San Juan	Dec 61	5728	78	Gallup	40						6800	Dakota	
Ballard Pic Cliffs;San Juan	Dec 53	2000	50	Pictured Cliffs	56	ML	SS	3	20	SGD	2183	Pic Cliffs	64000
Barker Creek Dakota; San Juan	Jan 42	2425	75	Dakota	58	AC/F	SS	14	16	SGD	9670	[illegible]	3000
Barker Creek Paradox; San Juan	Mar 45	8840	60	Paradox	58	AC/F	Do-Lm	25	6	SGD	9696	Penn	7380
Barker Dome South Tocito; San Juan	Sep 55	2336	64	Tocito	37	MF	Sh	P	f	GS	2400	Mancos	
Basin Dakota; San Juan-Rio Arriba	Dec 47	6000	250	Dakota	66	MC	SS	P	10	SGD	8150	Pre-Cambrian	368160
	May 62	7854	68	Dakota	63								
	Nov 62	6378	46	Dakota									
Bisti L Gallup; San Juan	Oct 55	4760	200	Gallup	41	ML	SS	30	15	SGD	5806	Morrison	16120
Blanco; Rio Arriba-San Juan	Dec 27	4600	800	Mesaverde	35	ML	SS	2	10	SGD	8164	Dakota	623000
	Jan 51	2500	80	Pictured Cliffs		ML	SS	3	18	SGD			
	Dec 52	7373	200	Dakota	58	ML	SS	0.5	8	SGD			
Blanco Dakota; San Juan	Oct 52	7796	218	Dakota	58	ML	SS	0.5	8	SGD	8096	Dakota	640
Blanco Mesaverde; Rio Arriba-San Juan	Dec 27	4600	750	Mesaverde	38	ML	SS	2	10	SGD	8164	Dakota	621440
Blanco Pic Cliffs; San Juan	Apr 52	2902	26	Pictured Cliffs		ML	SS	3	18	SGD	4550	[illegible]	8320
Blanco East Pic Cliffs; Rio Arriba	Feb 52	4170	185	Pictured Cliffs		ML	SS	1	15	SGD	4386	Pic Cliffs	3520
Blanco Northeast; San Juan	Oct 52												
Blanco South Dakota; Rio Arriba	Sep 51	7150	200	Dakota	58	ML	SS	0.[illegible]	8	[illegible]	7637	[illegible]	
	May 52	7485	113	Dakota	58	ML	SS	0.[illegible]	8	[illegible]			
Blanco South Pic Cliffs; Rio Arriba-San Juan	Dec 51	2136	70	Pictured Cliffs		ML	SS	3	20	SGD	6748	[illegible]	[illegible]
Blanco South Tocito; Rio Arriba	Jul 51	6622	16	Tocito	30	ML	SS	66	15	SGD	7637	[illegible]	3620
Blanco West Dakota;San Juan	Oct 61	6740		Dakota	55	ML	SS	0.5	8	SGD			
Bloomfield Farmington; San Juan	Jul 26	718	18	Farmington	58	ML	SS	2	12	SGD	2100	Pic Cliffs	3000
Bluebill Paradox; San Juan	May 53	7040	40	Paradox	58	AC	Lm	2	8	SGD	8180	Molas	640
Boulder Mancos; Rio Arriba	Jul 61	5200		Gallup	37						5264	Gallup	920
Canyon Largo (T) Chacra; Rio Arriba	Jan 58	3506	12	Chacra		ML	SS	2	11	SGD	7221	Morrison	
Canyon Largo Pic Cliffs Rio Arriba	Apr 53	2200	680	Pic Cliffs-Dakota		ML	SS	5	18	SGD			
Cedar Hills, San Juan	Sep 50	4780	191	Point Lookout							4981	Pt Lookout	320
Cha Cha Gallup; San Juan	Oct 59	5270		Gallup	38						5722	Mancos	7760
Chaco Canyon Tocito; San Juan	Oct 58	4630	140	Tocito	40	ML	SS	0.5	10	SGD	5830	Morrison	2560
Chaco Wash Mesaverde; McKinley	Sep 61	312	4	Mesaverde	48								240
Chimney Rock (T); San Juan	Feb 53	7604	24	Penn Paradox	58	AC	Lm	2	8	SGD	8150	Penn	160
Chimney Rock Gallup; San Juan	Dec 57	963	38	Gallup	45	ML	SS	50	12	SGD	1800	Morrison	
		472	16	Gallup	45	ML	SS	150	20	SGD			
Choza Mesa Pic Cliffs; Rio Arriba	Sep 55	3912	233	Pictured Cliffs		ML	SS	5	20	SGD	6580	Mancos	
Companero Dakota;Rio Arriba	May 52	7706	173	Dakota	56	ML	SS	0.3	8	SGD	7861	Dakota	1440
Companero East Dakota; Rio Arriba	Sep 55	8091	321	Dakota	55	ML	SS	0.3	8	SGD	8330	Morrison	
Cottonwood (Rosa) Fruitland; Rio Arriba	Nov 53	2875	189	Fruitld-Pic Cliffs		MC	SS	P	por	SGD	3684	Mesaverde	160
Counsellor's Gallup NE; Rio Arriba	Mar 58	5540	48	Gallup	41	MC	SS	0.2	9	SGD	6685	Dakota	160
Counsellor's Gallup SE; Sandoval	Feb 58	5293	45	L Gallup	41	MC	SS	0.5	10	SGD	5503	Gallup	
Devil's Fork Gallup; Rio Arriba	Oct 58	5240	96	Gallup		ML	SS	38	15	SGD	6561	Dakota	3920
Dogie Canyon; Rio Arriba	Jun 51	2861	80	Pictured Cliffs							7795	Morrison	8000
Escrito Gallup; Rio Arriba	Jun 57	5580	25	Gallup	41	ML	SS	0.5	9	SGD	6958	Morrison	3760
Farmington South Gallup; San Juan	Jul 58	5335	162	Gallup	42	ML	SS	10	15	SGD	6381	Dakota	
Flora Vista Fruitland; San Juan	Dec 56	1750	18	Fruitland	58	ML	SS	2	12	SGD	4368	[illegible]	1600
Flora Vista Mesaverde; San Juan	Feb 61	3250	64	Mesaverde							6574	Dakota	3200
Four Corners Paradox Penn; San Juan	56	5606	24	U Hermosa	43	AC	Lm	P	9	SGD	6850	Devonian	360
Fulcher Basin; San Juan	24	(See Fulcher-Kutz)											
Fulcher-Kutz; San Juan	Nov 27	1600	30	Pictured Cliffs		ML	SS	3	16	SGD	8043	Morrison	92800
		4348	100	Mesaverde									
Gallegos Fruitland;San Juan	Mar 52	1670	15	Fruitland		MC	SS	2	14	SGD			3560
Gallegos Gallup; San Juan	Jul 58	5360	82	Gallup	41	MC	SS	0.2	9	SGD	6064	Dakota	17280
Gavilan Pic Cliffs; Rio Arriba	Jul 49	3425	57	Pictured Cliffs		MC	SS	5	18	SGD	3574	Lewis Sh	12480
Gomez; Rio Arriba	Jun 52	3092	110	Fruitland							3485	Pic Cliffs	360
Hammond; Rio Arriba	Feb 32	3197	93	Pictured Cliffs							3290	Pic Cliffs	320
Hart Mountain; San Juan	Dec 50	4981	108	Cliff House							5177	Cliff House	320

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA 1962: Total oil, gas, gas cond wells drilled all yrs	Oil, gas, gas cond wells drld	Wells producing: Flowing	Wells producing: Artif lift	Wells producing: Gas	Wells abd: Drld dry	Wells abd: Abd prod wells	OIL AND GAS CONDENSATE PRODUCTION — Crude oil: Bbls in 1962	Crude oil: Cumulative bbls to 1/1/63	Condensate: Bbls in 1962	Condensate: Cumulative bbls to 1/1/63	GAS PRODUCTION — Dry gas: MCF in 1962	Dry gas: Cumulative in MCF to 1/1/63	Casinghead gas: MCF in 1962	Casinghead gas: Cumulative in MCF to 1/1/63
1	Comb w/Blanco Mesaverde 1953													
1	Comb w/Blanco E 1954													
6	Comb w/Basin Dakota Nov 1960									167,656		8,764,791		
31	0	18	3	0			55,948	338,602					4,111,166	18,963,411
5				31										
33	1	0	33						0	3,114	708,251	4,978,566		
6	Abd 1958										0	15,138		
381	14	0	0 NR	380		1			104	2,181	10,193,863	89,528,534		
428	8	0	0	428	1				0	27,814	12,019,562	116,936,210		
14	Gas Storage											7,132,413		
9	0	0	0	9					0	63,150	888,707	80,216,086		
	Renamed Verde-Gallup 1956													
964	248			836	6	3			1,160,806	3,318,066	88,260,882	219,737,683		
408	4			80	287		2,637,903	23,843,151					11,392,281	55,216,802
547	Divided into Blanco Mesaverde & Blanco E 1954													
1	Comb w/Blanco 1953													
1942	44			1942	1	7			454,039	4,823,390	131,848,158	1,483,274,381		
53	12			50	1				1,079	1,346	5,780,383	18,443,945		
22	0	0	0	21					0	287	850,487	8,446,937		
	Comb w/Blanco Mesaverde 1952													
9	Comb w/Basin Dakota Nov 1960									41,383		4,094,858		
1053	66	0	0	1033	1	1			1,444	35,848	36,490,807	380,965,603		
33	2	8	4	0			131,243	3,495,272					1,248,468	6,621,106
	Comb w/Basin Dakota Nov 1960											28,215		
4	0	0	0	0			0	2,302						
1	0	0	0	1							38,986	1,221,724		
33			1	13			263,421	384,147			104,298	119,904		
42	Comb w/Ballard Pictured Cliffs 1960											4,530,085		
	Comb w/Blanco													
97	8	29	37	0			1,077,025	4,143,523					4,810,676	9,775,354
5	Abd 1957													
6	0	0	4	0			1,811	2,723					716	
1	0	0	0	31										
	Comb w/Horseshoe Canyon Gallup 1959													
6	0	0	0	8							136,333	1,408,976		
1	Comb w/Basin Dakota Nov 1960									1,372		717,895		
4	Comb w/Basin Dakota Nov 1960									734		557,363		
1	[illegible]													
2	0	0	2	0			629	7,088					2,816	
1	0	0	1	0			501	3,368						
27	6	17	5	0			141,388	308,757					2,312,861	6,372,953
39	Comb w/Blanco S Pictured Cliffs													
47	6	23	26	0	1		397,324	1,194,889					2,083,644	3,864,503
1	Comb w/Cha Cha Gallup 1960													
5	0	0	0	5					0	0	42,845	800,462		
10	0	0	0	10							1,828,485	2,458,618		
1	0	1	0	0			3,600	74,080					4,702	118,385
	See Flucher-Kutz													
330	0	0	0	325		1			328	3,078	4,309,097	137,415,438		
1	0	0	0	1					0	13	23,873	507,086		
100	0	69	35	0			88,584	1,146,484					2,844,132	13,990,940
78	7	0	0	78		1			6,951	40,802	2,685,356	13,610,440		
1	Comb w/La Jara Fruitland													
1	Comb w/Blanco South 1953													
1	Comb w/Blanco 1952													

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TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD; COUNTY	DISCOVERY MO. - YR.	GEOLOGY: PRODUCING FORMATIONS: AVG. TOP FT	AVG. THK. *AVG. PERFS IN FT	GEOLOGICAL [illegible]	AVERAGE API GRAV	RESERVOIR CHARACTERISTICS: STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	DEEPEST TEST: TOTAL DEPTH	GEOLOGICAL FORMATION	TOTAL PROVED ACRES
Hogback Dakota; San Juan	Sep 22	710	9	Dakota	56	AC/T	SS	10	19	SGD	7453	Pre-Cambrian	960
Hogback Miss; San Juan				Miss		AC/T	Ls-Do	2	10	WD			
Hogback Penn; San Juan	Mar 54	6166	466	Penn		AC/T	Ls	5	12	SGD	7453	Pre-Cambrian	1440
Horseshoe Canyon Gallup; San Juan	Nov 56	1300	24	U Gallup	43	ML	SS	50	17	SGD	2085	Morrison	13120
			18	L Gallup	43	ML	SS	175	20	SGD			
Hospah Gallup; McKinley	Dec 26	1560	48	Hospah	30	AC/T	SS	250	25	WD	3282	Dakota	3200
Huerfano Dakota; San Juan	Oct 60	6776	24	Dakota	55	ML	SS	0.5	10	SGD	7072	Morrison	480
Ignacio South; San Juan	Jul 53	2766	40	Fruitland		AC/T	SS	P	por	SGD	5002	Mesaverde	160
Kutz Farmington; San Juan	Nov 55	1105	13	Farmington	58	MC	SS	5	15	SGD	1831	Pic Cliffs	1760
Kutz Fruitland; San Juan	Aug 56	1330	18	Fruitland									1920
Kutz Gallup; San Juan	Apr 58	5375	72	Gallup	37	MC	SS	1	11	SGD	6770	Morrison	2880
Kutz West Dakota; San Juan	Feb 52	5989	144	Dakota	55	ML	SS	1	10	SGD	6188	Dakota	
Kutz West Fruitland; San Juan	Oct 52	900	78	Fruitland		MC	SS	2	15	SGD	2042	Pic Cliffs	3720
Kutz West Pic Cliffs; San Juan	May 50	1771	69	Pictured Cliffs		ML	SS	3	16	SGD	6830	Morrison	57600
Kutz Canyon; San Juan	Nov 27	(See Fulcher-Kutz)											
Kutz Canyon South; San Juan	Oct 50	2042	68	Pictured Cliffs							6850	[illegible]	160
Kutz Canyon West; San Juan	May 50	1771	69	Pictured Cliffs		ML	SS	3	10	SGD	6830	[illegible]	57600
	Mar 52	1672	10	Fruitland		ML	SS	2	15	SGD			
		5880	80	Dakota	58	ML	SS	1	10	SGD			
La Jara Fruitld; Rio Arriba	Jun 52	3092	10	Fruitland		MC	SS	P	por	SGD			
La Jara Pic Cliffs; Rio Arriba	Oct 53	3830	30	Pictured Cliffs		MC	SS	P	por	SGD	6445	Mesaverde	160
La Plata; San Juan	Sep 49	6040	270	Point Lookout		MC	SS	3	12	SGD	6312	Pt Lookout	320
La Plata Gallup; San Juan	Apr 59	5700		Gallup	40						6200	Gallup	320
La Plata NW(T) Gallup; San Juan	Sep 56	2533	120	Gallup	41	MC	Sh	pfrc	f	SGD			
La Plata South; San Juan	Jul 50	4535	318	Point Lookout							4830	Pt Lookout	320
Largo; San Juan	Jan 50	4435	232	Point Lookout							4667	Pt Lookout	320
		4629	83	Mesaverde	36	ML	SS	3	13	SGD			
Largo Dakota; San Juan	Apr 58	6740	16	Dakota	56	ML	SS	1	10	SGD	6964	Morrison	160
Largo East; Rio Arriba	Dec 50	4884	136	Point Lookout							5210	Pt Lookout	320
Largo West; San Juan	Apr 50	4495	152	Point Lookout							4736	Pt Lookout	320
La Ventana; Rio Arriba	Feb 56	3784 3900	31	La Ventana		ML	SS	2	12	SGD	7505	Morrison	320
Lindrith Dakota; Rio Arriba	Dec 49	7518	215	Dakota	60	ML	SS	8	12	SGD	7865	Morrison	2560
Los Pinos North Dakota; [illegible]	Aug 54	7930	54	Dakota	55	ML	SS	0.2	5	SGD			
Los Pinos North Fruitland; [illegible]	Jul 53	2764	40	Fruitland		ML	SS	3	14	SGD	8002	Mesaverde	160
Los Pinos South Dakota; San Juan	Oct 54	7790	205	Dakota	58	ML	SS	0.2	6	SGD	8095	Morrison	
Los Pinos South Fruitland; San Juan	Aug 53	3054	21	Fruitland		ML	SS	3	14	SGD	3240		160
Lybrook Gallup; Rio Arriba	Aug 57	5715		Gallup	37						5896	Gallup	400
Media; Sandoval	Nov 62	2830		Gallup	[illegible]						9684	Pre-Cambrian	80
Mesa Gallup; San Juan	Aug 61	1013	16	Gallup	[illegible]						1482	Carlile	480
Oswell Farmington; San Juan	Jan 32	1342		Farmington Ss	55	ML	SS	2	13	SGD	1455	Farmington	2560
Otero Chacra; Rio Arriba	Feb 56	3700	31	Chacra-LaVentana		ML	SS	5	12	SGD	7505	Morrison	6880
Otero Dakota; Rio Arriba	Oct 54	6663	12	Dakota	55	ML	SS	2	10	SGD	7658	Entrada	
	Feb 57	7022	26	Dakota	55	ML	SS	5	13	SGD			
Otero Gallup; Rio Arriba	Aug 56	6380	10	Gall[illegible]	42	ML	SS	1	10	SGD	7743	[illegible]	4800
Otero Graneros, Rio Arriba	Aug 55	7110	22	Dakota (Graneros)	[illegible]	ML	SS	2	10	SGD	7484	Morrison	1400
Otero Pic Cliffs, Rio Arriba	Feb 55	2218	52	Pictured Cliffs		ML	SS	3	16	SGD	2270	Pic Cliffs	1600
Otero Pt Lookout, Sandoval	Jan 55		16	Point Lookout	37	ML	SS	2	12	SGD			160
Otero Sanostee; Sandoval	May 55	5820	20	Sanostee	37	ML	SS	2	10	SGD	6368	Morrison	1280
Puerto Chiquito; Rio Arriba	Jan 60	1785	39	Gallup	37	MF	Sh	P	f	GS	4830	Gallup	960
	Jun 60	3419	52	Greenhorn	38								
Rattlesnake Dakoka; San Juan	Feb 24	840	11	Dakota	55	AC/T	SS	14	17	SGD	7407	Penn	960
Rattlesnake Penn; San Juan	Jun 29	6585	10	Hermosa		AC/T	Ls	1	8	SGD	7407	Devonian	2460
Red Mountain; McKinley	Jun 34	490	6	Mesaverde	35	AC/T	SS	5	15	SGD	971	Mesaverde	2560
Salt Creek Dakota; San Juan	Jul 56	1039	4	Dakota	34						8175	[illegible]	160
San Luis Mesaverde, Sandoval	Apr 59	891	27	Mesaverde	38	AC/T	SS	P	por	WD	918	Mesaverde	160
Shiprock Gallup, San Juan	Mar 59	90	10	Gallup	30	ML	SS	10	15	SGD	100	Gallup	
Simpson Gallup; San Juan	Feb 59	5340	72	Gallup	41						6343	Dakota	200
Southern Ute Dome Dakota, San Juan	Oct 21	2200	80	Dakota	55	AC/T	SS	14	16	SGD	8802	Penn	640
Starr Lake Mesaverde; McKinley	Apr 58	1805	10	Mesaverde	39	ML	SS	5	15	SGD	1949	Mesaverde	
Stephenson (T); Rio Arriba	Jul 57	2931	40	Greenhorn Ls							3292	Dakota	
Stoney Butte Dak. San Juan	Sep 50	3639	5	Dakota	42	AC/f	SS	10	16	WD	9346	Pre-Cambrian	40
Table Mesa Dakota; San Juan	Nov 25	1360	12	Dakota	55	AC/T	SS	14	16	SGD	7763	Granite	640
Table Mesa Miss; San Juan		7450	80	Miss		AC/f	Ls-Do	P	por	WD	7789	Elbert	
	[illegible] 62	7676	22	Miss	59								
Tapacitos; Rio Arriba	Dec 53	6985	46	Dakota		ML	SS	0.5	10	SGD	8043	Morrison	1760
		8090	108	Dakota		ML	SS	0.5	10	SGD			
Tapacitos Pic Cliffs; Rio Arriba	May 54	3557	62	Pic Cliffs		ML	SS	10	18	SGD	8041	Morrison	21120
Torreon, Sandoval	Jan 53	945	29	Mesaverde		[illegible]	SS	P	por	WD			160
Torreon Entrada, Sandoval	Nov 53	5210	5	Entrada		MF	SS	H	por	WD	9684	Entrada	80
Torreon Mesaverde, Sandoval	Dec 53	1672	13	Mesaverde		MF	SS	P	por	WD	1683	Mesaverde	40
Totah Gallup, San Juan	Sep 59	4900	62	Gallup	41						6030	Morrison	5200
Twin Mounds Mesaverde, San Juan	Feb 54	3348	10	Point Lookout	35	[illegible]	SS	5	12	SGD	5760	Morrison	320
Twin Mounds Pic Cliffs, San Juan	Jul 54	921	18	Pic Cliffs		[illegible]	SS	3	16	SGD	3512	Pic Cliffs	40
Ute Dome Dakota, San Juan	Oct 21	2190	285	Dakota	55	[illegible]	SS	14	16	WD	8602	Penn	2560
Ute Dome Paradox, San Juan	Aug 48	7300	1000	Paradox Penn	52	DF	Ls	P	5	WT	8602	[illegible]	2560
Verde Gallup, San Juan	Sep 55	2336	64	Tocito	42	MF	Sh	pfrc	f	SGD	2833	Morrison	9000

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA: Total oil, gas, gas cond wells drilled all yrs	Oil, gas, cond wells field	Wells producing: Flowing	Wells producing: Artif lift	Wells producing: Gas	Wells abd.: Drld dry	Wells abd.: Abd. prod. wells	Crude oil: Bbls in 1962	Crude oil: Cumulative bbls to 1/1/63	Condensate: Bbls in 1962	Condensate: Cumulative bbls to 1/1/63	Dry gas: MCF in 1962	Dry gas: Cumulative in MCF to 1/1/63	Casinghead gas: MCF in 1962	Casinghead gas: Cumulative in MCF to 1/1/63
10	0	10	0	0			54,936	3,664,509						
	Abandoned													
2	0	2	0	0			16,857	357,927					29,550	3,370,244
378	0	0	299	0			2,327,517	14,227,033					1,436,726	5,887,316
46	0	0	42	0			101,556	4,233,808						
1	Comb w/Basin Dakota Nov 1960									18,290		725,984		
1	Comb w/Los Pinos W Fruitland													
5				3							18,287	183,499		
4				4					0	220	165,018	1,083,218		
19	0	7	11	0			73,156	406,864					304,848	909,161
3	Comb w/Basin Dakota Nov 1960									11,768		406,745		
3	0	0	0	3							27,234	217,446		
210	0	0	0	211		4					0	341	3,324,643	74,415,972
	See Fulcher-Kutz													
	Comb w/Kutz Canyon West													
182	Divided into Kutz W Dakota, Kutz W Fruitland 1954													
	Abd 1955,Recomp as Blanco Mesaverde field well													
1	Comb w/La Jara Fruitland													
	Comb w/Blanco 1949													
1	0	0	1	0			34,960	119,760					14,217	
	Comb w/Blanco 1951													
	Comb w/Blanco 1951													
1	Abd 1950										0	80,916		
	Comb w/Blanco 1950													
	Comb w/Blanco													
2	Name changed to Otero Chacra 1966													
4	0	0	1	0			160	27,141					457	
	Comb w/Basin Dakota Nov 1960							6,332,687						
1	0	0	0	1							12,175	208,628		
3	Comb w/Basin Dakota Nov 1960											415,806		
1	0	0	0	1							30,114	284,542		
10	0	4	6	0			40,265	95,152					402,349	
2	2	0	2	0			1,537	1,537					156	155
12	0	0	9	0			60,386	63,946						
8	0	0	1				803	8,626						
28	5	0	0	28					0	2,362	1,733,791	7,861,073		
	Comb w/Basin Dakota Nov 1960									199,338		3,822,106		
42	0	2	40	0			134,584	979,497					891,415	4,052,516
	Comb w/Otero Dakota							7,516		93,403		1,823,835		
	Comb w/Ballard Pictured Cliffs 1960											11,538,630		
2	Abd 1961						0	18,352						
3	Abd 1961						0	29,882						
14	0	0	12	0			93,161	111,537*					873	
85	0	1	29	0	1		9,660	4,642,797					14,886	
11	7	3	5	0		3	161,419	680,127						
21	7	1	13	0			52,687	85,649						
4	0	0	3	0			3,014	40,055						
4	0	0	3	0	3		3,014	40,055						
40	0	0	38	0	2		15,101	37,172						
5	0	1	4	0			80,945	160,309					136,582	
5	Comb w/Ute Dome Dakota													
	Abd 1959													
1	Abd 1953						0	366						
1	Abd 1952						0	9,887						
14	1	0	12 HR	0			55,763	1,185,141						
11	Comb w/Basin Dakota													
132	20	0	0	132					140	26,371	6,997,512	63,791,393		
	Abd 1961						0	350						
2	Abd Dec 1955						0	13,875						
1	Abd													
65	3	33	23	0	1		465,904	2,383,848					2,437,847	5,376,762
1	Abd 1956								0	4,575	0	652,995		
2	Abd 1956													
5	0	0	0	5					0	2,830	67,240	3,141,449		
				2(SI)							0	0		
197	0	0	137	0	1	8	504,327	6,207,122					318,044	

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TABLE 5.—*Oil and gas fields in New Mexico*—Continued

FIELD; COUNTY	DISCOVERY MO - YR	GEOLOGY												
		PRODUCING FORMATIONS				RESERVOIR CHARACTERISTICS					DEEPEST TEST		TOTAL PROVED ACRES
		AVG TOP FT	AVG THK *AVG PERFS IN FT	GEOLOGICAL FORMATION	AVERAGE API GRAV	STRUCTURE	CHARACTER	PERMEABILITY MILLIDARCIES	% POROSITY ESTIMATED	PRODUCTION MECHANISM	TOTAL DEPTH	GEOLOGICAL FORMATION	
Walker Dome Los Mancos; McKinley	Aug 36										975	Mancos	
Vyper; San Juan	Aug 46	300	10	Farmington Ss	33	[illegible]	[illegible]	5	16	[illegible]			2560
Not Named; Rio Arriba	Dec 62	6250		Gallup	38						6398	Mancos	80
Not Named, Rio Arriba	Aug 60	6425	125	Gallup	42						7830	Dakota	640
Not Named, San Juan	Aug 59	1500	7	Fruitland							1826	Pic Cliffs	160
Not Named, Rio Arriba	Aug 62	600	30*	Morrison							1401	Entrada	320
Not Named, San Juan	Jun 59	4740		Gallup	39	[illegible]	[illegible]	7	por	[illegible]	5904	Morrison	
Not Named, San Juan	Nov 62	1240	11*	Gallup	40						1300	Mancos	40
Not Named; McKinley	Aug 60	3070		Gallup	40								40
Not Named, Rio Arriba	Apr 57	7264	30	Gallup	43	[illegible]	[illegible]	0.5	9	[illegible]	7366	Gallup	320
Not Named; Sandoval	Aug 57	4730	12	Gallup Sd	35						5860	Morrison	160
Not Named, San Juan	Apr 59	5840		Paradox	73	AC/F	Ls	7	6	[illegible]	7026	Miss	640
Not Named, McKinley	May 60	2172	28	Mancos	46						3436	Gallup	40
Not Named, San Juan	Apr 60	3646	283	Gallup	48						6937	Dakota	40
Not Named; Rio Arriba	May 60	2125	224	Gallup	37						2136	Gallup	40
Not Named; Rio Arriba	May 62	8160	48*	Dakota							8330	Dakota	320
Not Named; San Juan	Oct 59	3800		Gallup	38	[illegible]	[illegible]	1	11	[illegible]	4887	Morrison	160
Not Named, Sandoval	Aug 56	5331	18	Gallup	40	[illegible]	[illegible]	0.5	9	[illegible]	5515	Gallup	80
Not Named; Rio Arriba	Jan 60	8046	88	Dakota2	44						8350	Dakota	160
Not Named; San Juan	Sep 58	6300		Dakota	43						8706	Morrison	120

TABLE 5.—*Oil and gas fields in New Mexico*—Continued

WELL DATA 1962							OIL AND GAS CONDENSATE PRODUCTION				GAS PRODUCTION			
TOTAL OIL, GAS, GAS COND WELLS DRILLED ALL YRS	OIL, GAS, GAS COND WELLS DRLD	WELLS PRODUCING			WELLS ABD		CRUDE OIL		CONDENSATE		DRY GAS		CASINGHEAD GAS	
		FLOWING	ARTIF LIFT	GAS	DRLD DRY	ABD PRODUCERS	BBLS IN 1962	CUMULATIVE BBLS TO 1/1/63	BBLS IN 1962	CUMULATIVE BBLS TO 1/1/63	MCF IN 1962	CUMULATIVE IN MCF TO 1/1/63	MCF IN 1962	CUMULATIVE IN MCF TO 1/1/63
	Abd-Never Produced													
2	Abd													
2	0	0	2	0			1,426	1,426						
8	0	0	8	0			32,079	112,196						
1	0	0	0.	1							7,070	36,318		
1	1	Abd 1962				1								
	Abd 1962						0	4,362						
1	1	0	1	0	0	0	1,048	1,048						
1	0	0	1	0			573	758						
2	Abd 1961										0	26,108		
2	0	0	2	0			1,443	11,023			198			
1	0	0	0	1	0		370,460	2,321,600						
1	Abd 1962					1	0	20						
1	0	0	1	0			2,571	9,527						
1	0	0	SI				0	140						
1	1	0	0	SI										
2	0	0	2	0			2,631	6,101						
1	Abd						0	2,990						
2	0	2	0	0			16,443	28,335					97,657	
2	0	1	1	0			2,508	30,011						

A reserves study by the American Petroleum Institute and the American Gas Association indicates that New Mexico had 1,010,729,000 barrels of crude oil reserves as of December 31, 1963, and 588,223,000 barrels of natural gas liquid reserves, for a total hydrocarbon liquid reserve of 1,568,962,000 barrels. Natural gas reserves were estimated to be 15,037,822,000,000 cubic feet as of December 31, 1963. (See tables 6, 7, and fig. 15.)

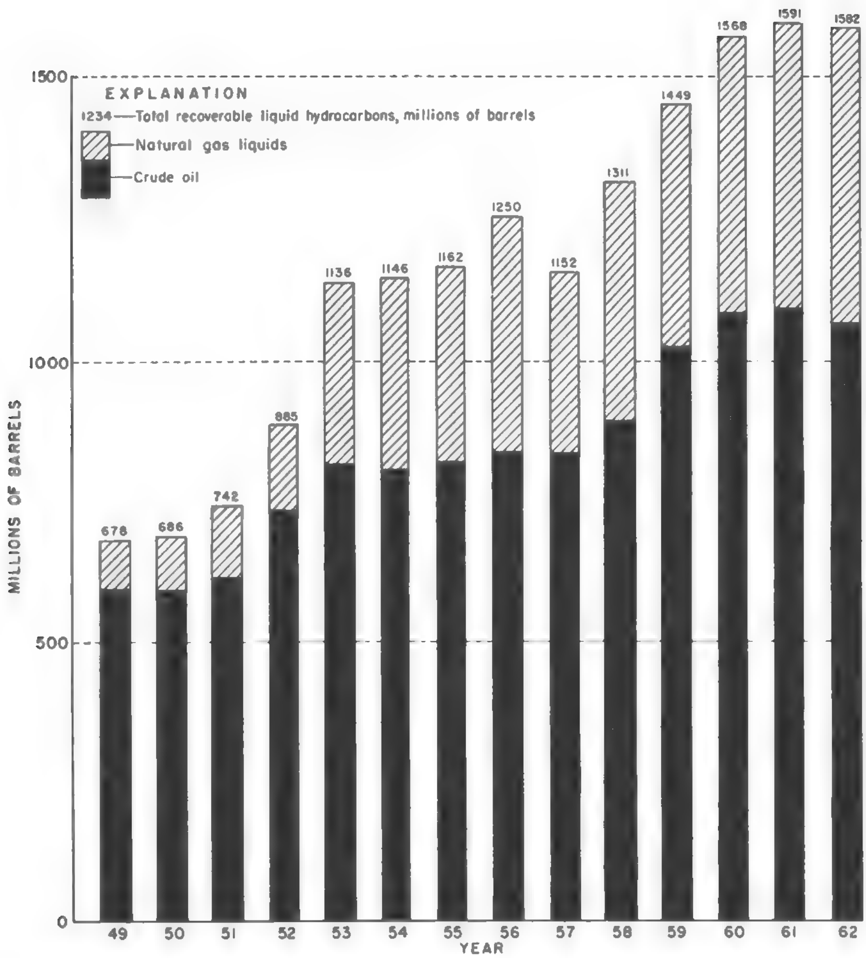

FIGURE 15.—Recoverable reserves of liquid hydrocarbons in New Mexico per calendar year. (Source of data: American Petroleum Institute.)

TABLE 6.—*Estimated proved crude oil reserves in New Mexico (in barrels)*

Year	Reserves at first of year	Changes due to extensions	New discoveries	Production during year	Reserves at end of year	Changes in total [illegible]
1949	552, 231, 000	46, 204, 000	41, 266, 000	47, 479, 000	592, 222, 000	39, 991, 000
1950	592, 222, 000	31, 065, 000	12, 418, 000	43, 723, 000	591, 982, 000	−240, 000
1951	591, 982, 000	63, 788, 000	9, 504, 000	53, 634, 000	611, 640, 000	19, 658, 000
1952	611, 640, 000	158, 663, 000	22, 905, 000	59, 850, 000	733, 358, 000	121, 718, 000
1953	733, 358, 000	138, 420, 000	13, 112, 000	69, 988, 000	814, 902, 000	81, 544, 000
1954	814, 902, 000	55, 647, 000	8, 131, 000	72, 794, 000	805, 886, 000	−9, 016, 000
1955	805, 886, 000	86, 016, 000	8, 576, 000	80, 820, 000	819, 658, 000	13, 772, 000
1956	819, 658, 000	81, 745, 000	21, 150, 000	87, 116, 000	835, 437, 000	15, 779, 000
1957	835, 437, 000	76, 992, 000	11, 750, 000	92, 435, 000	831, 744, 000	−3, 693, 000
1958	831, 744, 000	143, 759, 000	14, 406, 000	95, 788, 000	894, 121, 000	62, 377, 000
1959	894, 121, 000	222, 100, 000	11, 909, 000	102, 341, 000	1, 025, 789, 000	131, 668, 000
1960	1, 025, 789, 000	142, 951, 000	19, 187, 000	104, 269, 000	1, 083, 658, 000	57, 869, 000
1961	1, 083, 658, 000	88, 816, 000	26, 502, 000	108, 773, 000	1, 090, 203, 000	6, 545, 000
1962	1, 090, 203, 000	57, 565, 000	21, 615, 000	104, 793, 000	1, 064, 590, 000	−25, 613, 000
1963	1, 064, 590, 000	32, 487, 000	18, 111, 000	104, 459, 000	1, 010, 729, 000	−53, 861, 000

Source of data: American Petroleum Institute.

TABLE 7.—*Estimated proved liquid hydrocarbon reserves in New Mexico (in barrels)*

Year	Reserves at first of year	Changes due to extensions	New discoveries	Production during year	Reserves at end of year	Changes in total reserves
1949	632, 478, 000	55, 356, 000	42, 002, 000	51, 895, 000	677, 941, 000	45, 463, 000
1950	677, 941, 000	42, 838, 000	13, 788, 000	48, 688, 000	685, 879, 000	7, 938, 000
1951	685, 879, 000	108, 009, 000	10, 165, 000	61, 794, 000	742, 259, 000	56, 380, 000
1952	742, 259, 000	188, 352, 000	24, 252, 000	69, 962, 000	884, 901, 000	142, 642, 000
1953	884, 901, 000	316, 719, 000	14, 913, 000	80, 974, 000	1, 135, 559, 000	250, 658, 000
1954	1, 135, 559, 000	84, 551, 000	11, 707, 000	85, 940, 000	1, 145, 877, 000	10, 318, 000
1955	1, 145, 877, 000	102, 280, 000	9, 864, 000	96, 156, 000	1, 161, 865, 000	15, 988, 000
1956	1, 161, 865, 000	166, 319, 000	23, 639, 000	102, 287, 000	1, 249, 536, 000	87, 671, 000
1957	1, 249, 536, 000	−5, 578, 000	16, 093, 000	107, 759, 000	1, 152, 292, 000	−97, 244, 000
1958	1, 152, 292, 000	255, 774, 000	16, 149, 000	112, 856, 000	1, 311, 359, 000	159, 067, 000
1959	1, 311, 359, 000	238, 104, 000	20, 795, 000	121, 429, 000	1, 448, 829, 000	137, 470, 000
1960	1, 448, 829, 000	229, 085, 000	23, 159, 000	132, 616, 000	1, 568, 457, 000	119, 628, 000
1961	1, 568, 457, 000	134, 675, 000	27, 751, 000	139, 434, 000	1, 591, 449, 000	22, 992, 000
1962	1, 591, 449, 000	101, 932, 000	23, 425, 000	135, 007, 000	1, 581, 799, 000	−9, 650, 000
1963	1, 581, 799, 000	103, 936, 000	19, 515, 000	136, 288, 000	1, 568, 962, 000	−12, 837, 000

Source of data: American Petroleum Institute, and American Gas Association.

TABLE 8.—*Estimated proved natural gas reserves in New Mexico*

[Millions of cubic feet]

Year	Production	National rank	Reserves	National rank
1949	256, 706	6	6, 241, 003	6
1950	248, 245	6	6, 990, 670	6
1951	315, 835	6	11, 589, 970	5
1952	442, 043	6	14, 038, 889	4
1953	436, 102	6	17, 522, 210	3
1954	549, 760	4	17, 240, 669	3
1955	544, 175	4	18, 584, 912	3
1956	641, 880	4	23, 472, 707	3
1957	743, 826	4	22, 258, 009	4
1958	724, 628	4	21, 180, 020	3
1959	702, 514	4	17, 912, 798	4
1960	778, 760	4	15, 603, 724	5
1961	744, 400	4	14, 757, 739	5
1962	729, 288	5	14, 189, 797	5
1963	714, 648	5	15, 037, 822	5

Source of data: American Gas Association.

Refining of petroleum products in New Mexico shows an upward trend correlative with increasing petroleum production (figs. 16, 17, 18). Although much natural gas is exported by pipeline to other parts of the Nation, most of the gasoline produced in the State is consumed locally (fig. 19).

THE OIL AND GAS RESOURCES OF SOUTHEASTERN NEW MEXICO

(By **R.** F. Montgomery, Hobbs, N. Mex.)

INTRODUCTION

Since 1923 southeastern New Mexico has consistently been one of the most active areas in both exploration and development of oil and gas resources in the Nation. The area has the highest success ratio for wells drilled of all major producing provinces in the country, averaging 22 percent for the past 25 years. As a result Lea County produces more hydrocarbons than any county in the Nation. The oil and gas resources of southeastern New Mexico provide a major revenue source to New Mexico, which has one of the lowest tax rates on personal property and income in the country. A brief geologic sketch and information on production of oil and gas in southeastern New Mexico are presented. As used in this chapter southeastern New Mexico includes the oil and gas producing counties, Lea, Eddy, Chaves, and Roosevelt. Figure 20 shows the distribution of oil and gas fields in these counties.

GEOLOGY

Southeastern New Mexico is within the Permian basin. Paleogeographic features within the Permian basin, such as the Central Basin platform, the Delaware basin, the Lovington basin, and the Northwestern shelf (Figs. 7 and 24) are important to the control of regional distribution of oil and gas resources.

Central Basin platform.—The Central Basin platform is a large positive feature in the central part of the Permian basin. The platform is bordered on the west by the Delaware basin and on the north by the San Simon syncline, the site of a Permian channel connecting the Midland basin in Texas with the Delaware basin in New Mexico. The Central Basin platform was formed during Late Pennsylvanian time. Over the Eunice high sedimentary rocks about 6,000 feet thick were uplifted, and removed by erosion in Early Permian time. The Abo Formation, here consisting largely of dolomite, rests with angular unconformity on older rocks, including Precambrian basement rock on the eastern margin of the Eunice high.

Present oil and gas production from the Central Basin platform. area is from sedimentary rocks of Ordovician, Silurian, Devonian, and Permian ages (table 9). Prolific Upper Permian reservoirs include those of the Eunice-Monument, Dollarhide, and Hobbs fields. Many of the anticlines, such as Hobbs, Arrowhead, and Monument, are as yet incompletely tested in spite of the intensive development since 1926. The geologic setting of these structures is similar to that of the Eunice high where 11 zones produce oil and gas. The Dollarhide, Fowler, and Justis fields are productive in five formations and most fields on the Central Basin platform produce from more than one zone.

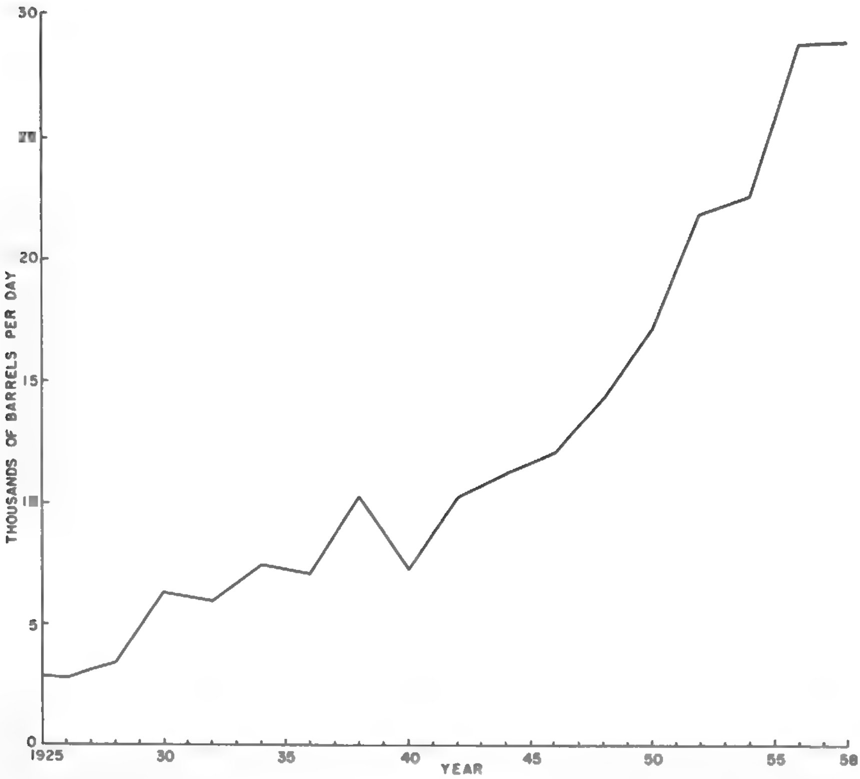

FIGURE 16.—Crude oil capacity of operating refineries in New Mexico. (Source of data: U.S. Bureau of Mines.)

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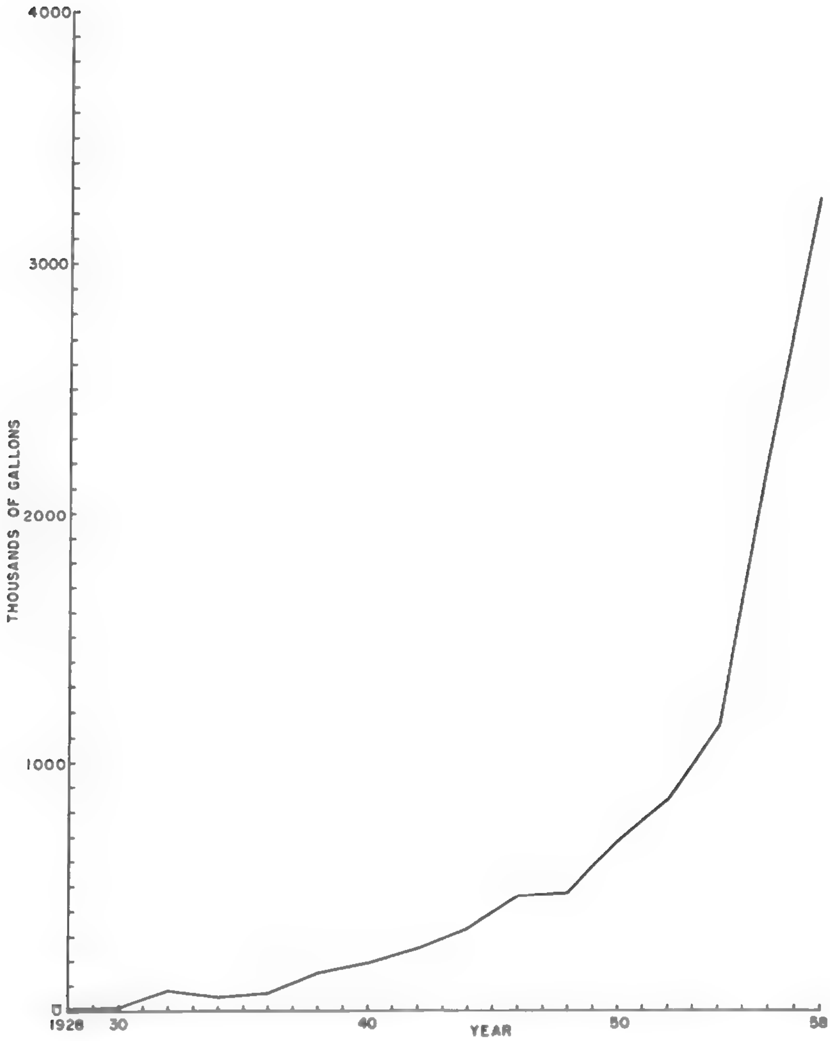

FIGURE 17.—Daily capacity of natural gasoline plants in New Mexico. (Source of data: U.S. Bureau of Mines.)

Of the 10 largest fields in accumulative production in New Mexico, the following 6 are on the Central Basin platform :

Rank	Field	Formation	Accumulated production to Jan. 1, 1964 (barrels)
1	Eunice-Monument	Grayburg-San Andres	266, 437, 051
2	Hobbs	Grayburg-San Andres	176, 702, 538
5	Langlie-Mattix	Seven Rivers-Queen	62, 109, 696
6	Drinkard	Drinkard	54, 119, 282
7	Jalmat	Yates-Seven Rivers	53, 120, 659
8	Eumont	Yates-Seven Rivers-Queen	51, 943, 951

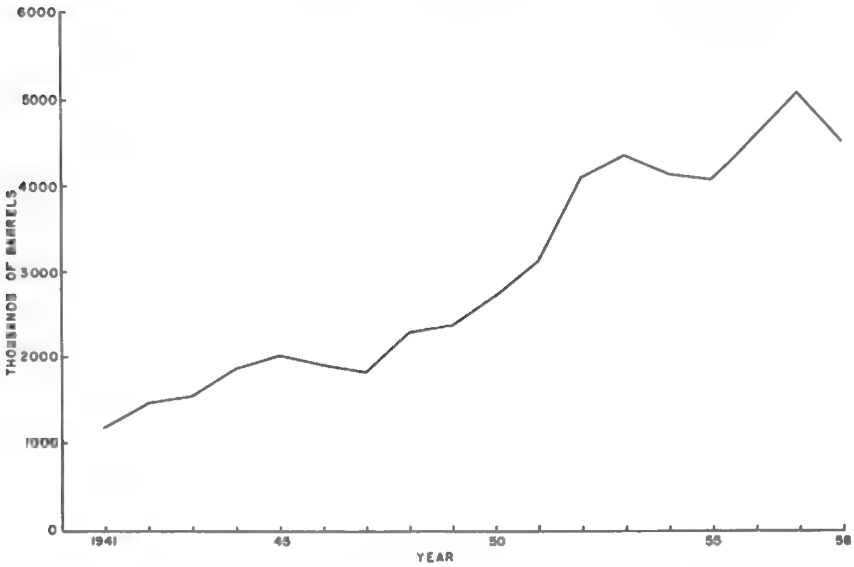

FIGURE 18.—Production of refined gasoline in New Mexico. (Source of data: U.S. Bureau of Mines.)

Northwestern shelf.—The Northwestern shelf is the relatively stable area north of the Delaware basin. Much of the oil and gas production is from back reef rocks of Guadalupe age that are similar in environment and depositional history to equivalent producing zones of the Central Basin platform. Other producing zones include older Permian, Pennsylvanian, and Devonian formations.

The hinge line of the Northwestern shelf and the Delaware basin was an area favorable for extensive reef and limestone banks that grew intermittently during part of the Pennsylvanian and most of Permian time.

Recently discovered major fields that produce oil from ancient reefs include Empire Abo, Vacuum Abo, and Lovington Abo. Producing

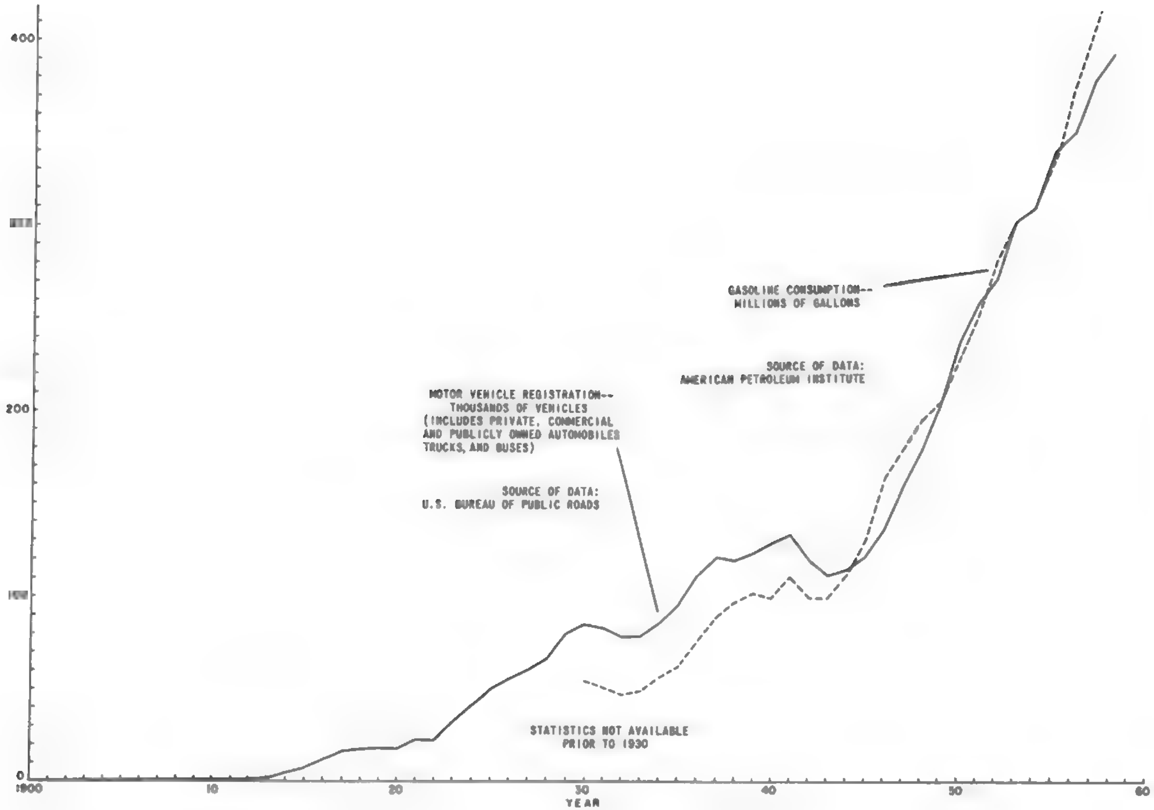

FIGURE 19.—Relationship of gasoline consumption to motor vehicle registration in New Mexico.

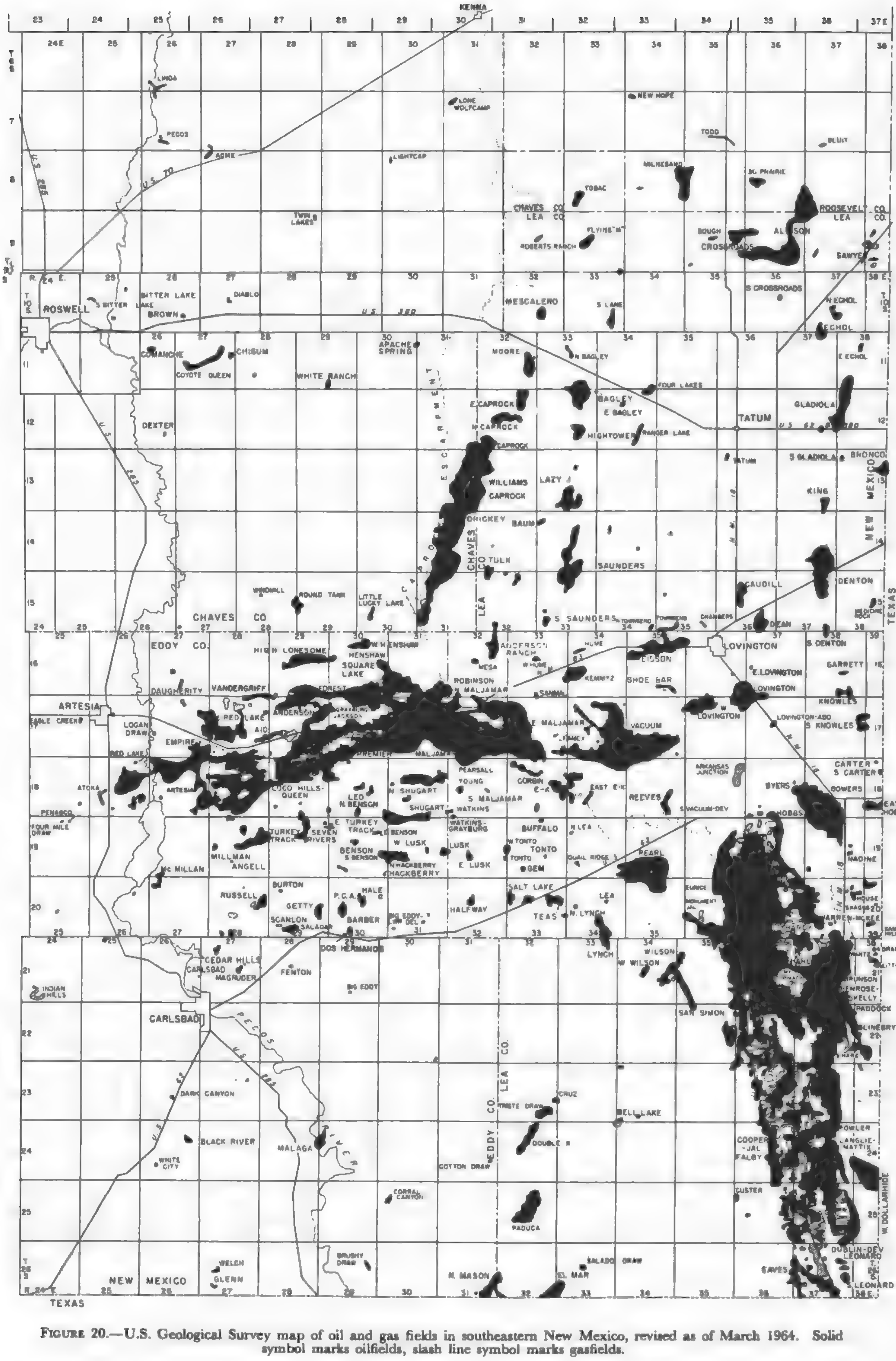

FIGURE 20.—U.S. Geological Survey map of oil and gas fields in southeastern New Mexico, revised as of March 1964. Solid symbol marks oilfields, slash line symbol marks gasfields.

zones in these fields are as much as 650 feet thick. Estimated per well recoveries of 1 million barrels are the rule.

Limestone banks and shoe-string sands of Guadalupe age (Late Permian) were discovered in the 1920's and 1930's and form some of the largest reservoirs in the State. Examples are the Vacuum field, which has produced 101 million barrels of oil and the Grayburg Jackson field, which has produced 50 million barrels of oil.

The hinge line on the eastern margin of the Northwestern shelf where the rocks dip into the Lovington basin is the site of the Anderson Ranch-SRR trend, along which occur numerous productive anticlinal structures whose reservoirs are in Devonian, Pennsylvanian, and Lower Permian rocks. Although these structures are small in area, the reservoirs are excellent; most wells producing from Devonian rocks in this area yield in excess of 1 million barrels each.

Stratigraphic traps have not been extensively explored in southeastern New Mexico; the Caprock Queen field produces from such a trap. The productive sands of this field cover an area 25 miles in length and 1 to 3 miles in width. The field has produced more than 45 million barrels of oil and is presently under a successful secondary recovery program.

Lovington basin.—The Lovington basin, a basin of Pennsylvanian age usually considered to be part of the Northwestern shelf, is bordered on the north by the Matador arch, on the west by the Northwestern shelf, and on the south by the Central Basin platform.

Development of oil and gas fields has been extensive along the margins of this basin. Anticlinal structures producing from Pennsylvapian and Devonian rocks contain the major reservoirs. Major producing fields in the area include Denton which has produced more than 91 million barrels of oil to date.

Potential areas of future production are present along the margins of the basin. Recent discoveries of oil in the San Andres Limestone on the north rim of this basin may be greatly expanded. The Ordovician and Silurian zones that are productive in southern Lea County have not been extensively tested in this area.

Delaware basin.—The Delaware basin contains the thickest section of rocks in southeastern New Mexico and is the last area to be explored. The first test to basement rocks was drilled in 1964 to a depth of 21,275 feet.

The Delaware basin is enclosed by Permian reefs and is bounded on the north and west by the Carlsbad shelf and on the east by the Central Basin platform. The Permian rocks of the Delaware basin grade into the transgressing Permian reefs. Lower Paleozoic rocks are of greater thickness than over the Northwestern shelf. To date lower Paleozoic rocks have not been extensively tested; however, they contain major reservoirs a few miles south in the Texas part of the Delaware basin.

Permian rocks of the Delaware basin include thick sequences of sandstone, black shale, black limestone, anhydrite, halite, and potash salts. The Capitan barrier reef that borders the Delaware basin is nearly 2,000 feet thick locally and is many miles in width.

Major reserves of gas-condensate have been discovered in the Delaware basin in lower Paleozoic rocks. Shallow stratigraphic reservoirs in sandstone of the Delaware Mountain Group of Permian (Guadalupe) age have been scattered but prolific.

TABLE 9.—*Nomenclature of oil and gas producing zones, southeastern New Mexico*

SYSTEM	SERIES	STRATIGRAPHIC UNIT		LEA COUNTY POOLS	EDDY COUNTY POOLS
		Basin	Shelf		
Permian	OCHOA	Rustler			
		Salado			
		Castile			Glenn
	Guadalupe	Bell Canyon	Tansill		Hale, Scanlon
			Yates	Arrow, Baish, Corbin, Eaves, Eumont, Gem, Halfway, Jalmat, Lusk, Lynch, North Lynch, Rhodes, San Simon, Teas, Wilson, North Wilson.	Aid, Barber, Benson, Burton (ABD), Cedar Hills, Empire, Getty, Hackberry, Lusk, W. Lusk, P.C.A., Russell, Shugart. (Black River, Dark Canyon, Fenton - Delaware Basin Malaga, Santa Nina)
			Seven Rivers	Arrow, Bowers, Cooper Jal, Eaves, Eumont, South Eunice, East Hobbs, Jalmat, Langlie Mattix, Leonard, Tonto, Watkins, West Wilson.	Aid, Angell, Empire, Fren, McMillan, Palimillo(ABD), Turkey Track - Seven Rivers.
		Cherry Canyon	Queen	Arrow, Caprock, North Caprock, Cooper Jal, Corbin, Dollarhide, Eumont, Langlie Mattix, South Leonard, Pearsall, Penrose Skelly, Young.	Culwin, Grayburg - Jackson, Highlonesome, McMillan, Shugart, North Shugart, Turkey Track, East Turkey Track, Loco Hills - Queen.
			Grayburg	Arrowhead, Eunice-Monument, Hardy, Hobbs, Maljamar, East Maljamar, North Maljamar, South Maljamar, Penrose Skelly, Roberts, Skaggs, Vacuum, Watkins.	Anderson, Artesia, Cave(ABD), Dayton, East Dayton (ABD), Grayburg-Jackson, South Highlonesome, Leo, Loco Hills, Maljamar, Millman, Premier, Red Lake, Robinson, Square Lake, Turkey Track.
		Brushy Canyon	San Andres	Eighty Four Draw, Eunice-Monument, Garrett, Hobbs, East Hobbs, House, Littman, Lovington, West Lovington, Maljamar, East Maljamar, North Maljamar, Sawyer, Vacuum.	Anderson, Artesia, Atoka, Daugherity, Forest, Grayburg - Jackson, Grayburg - Keely, Henshaw, South Highlonesome, Loco Hills, Logan Draw, Maljamar, Nichols, Red Lake, Robinson, Square Lake.
			"Glorieta" Sandstone	Justis, Lovington, Monument, Maljamar, Paddock.	

	Leonard	Bone Spring	Yeso includes Sandy Paddock	Blinebry, East Hobbs, Monument, Terry.	
				Tubb	
				Dollarhide, Drinkard, Fowler, Hobbs, House, Nadine, Skaggs, Warren, Weir.	
	WOLFCAMP	Abo - Hueco		Anderson Ranch, East Caprock, Denton, D-K, Gladiola, King, Lovington, Townsend, Tulk, Wantz.	
PENNSYLVANIAN				Allison, Bagley, Bough, Cass, Crossroads, Edison, Hightower, Lazy J, East Lovington, Mescalero, Moore, Saunders, South Saunders, Shoe Bar.	
MISSISSIPPIAN		"Mississippi limestone"		Denton	
DEVONIAN				Anderson Ranch, Bagley, Bronco, East Caprock, Crossroads, Denton, Dollarhide, Echol, North Echol, Gladiola, Hightower, Knowles, South Knowles, Maljamar, Mescalero, Moore, Shoe Bar, Teague.	
SILURIAN		Fusselman		Dollarhide, Fowler, McCormick.	
ORDOVICIAN	UPPER	Montoya		Cary	
	MIDDLE	Simpson		Hare, South Hare, Teague, Warren, North Warren.	
	LOWER	Ellenburger		Brunson, Dollarhide, Fowler, Teague	
PRECAMBRIAN					

It is anticipated that improved geophysical techniques will lead to more aggressive exploration in the future. The potential stratigraphic traps that occur on the margins of this vast basin will be major objectives of shallow exploration.

DEVELOPMENT

Oil was first discovered in the San Andres Limestone in New Mexico in 1909, eight miles south of Artesia. Due to mechanical problems, the discovery well was never completed. Fifteen years later commercial production was found in southeastern New Mexico. The Hobbs San Andres discovery of 1928 led to the development of the first major oil field. From this beginning, southeastern New Mexico became one of the major oil and gas producing areas of the Nation. The latest issue of the U.S. Department of Commerce Census of Mineral Industries records Lea County's annual oil and gas valuation at $266,400,000.

Due to the economic problems of the 1930's the oil industry in New Mexico suffered severely. From these difficulties came the basic regulatory concepts in which New Mexico took the lead, and consequently permitted New Mexico's oil industry to regain and maintain its economic health.

During the 1930's the Artesia-Vacuum trend was extended, as was shallow production on the Central Basin platform.

In 1944 production below the San Andres Limestone was discovered in the Cass pool ; during the late 1940's the deep fields of the Central Basin platform were discovered ; and from 1948 through the 1950's many prolific Devonian fields were discovered in the Lovington basin.

Significant shallow discoveries were made in the Delaware basin in 1950 and improved production techniques opened up areas of previously uneconomic production. This, along with secondary recovery, was the cause for large capital expenditures in the area throughout the 1950's and into the 1960's.

While improved secondary recovery techniques permitted continued development of older known fields, many new fields were discovered along established trends; in 1957 concepts of reef exploration resulted in the discovery of Empire Abo field, one of the few giant fields found in the Nation during the 1950's. This in turn led to other Abo reef discoveries and exploration continues today.

In 1960 the Lea Devonian field was discovered. This discovery was important for it established New Mexico's deepest economically significant oil production to date, below 14,000 feet.

The deepest well yet drilled in New Mexico, 21,275 feet, was drilled in 1964. It encountered large reserves of gas condensate in several zones. This is the first of many wildcat wells that will likely be drilled into the deepest parts of the relatively unexplored Delaware basin.

Figure 21 shows oil well completions and figure 22 shows oil allocation and production in southeastern New Mexico. Table 10 shows production of the 10 largest producing fields.

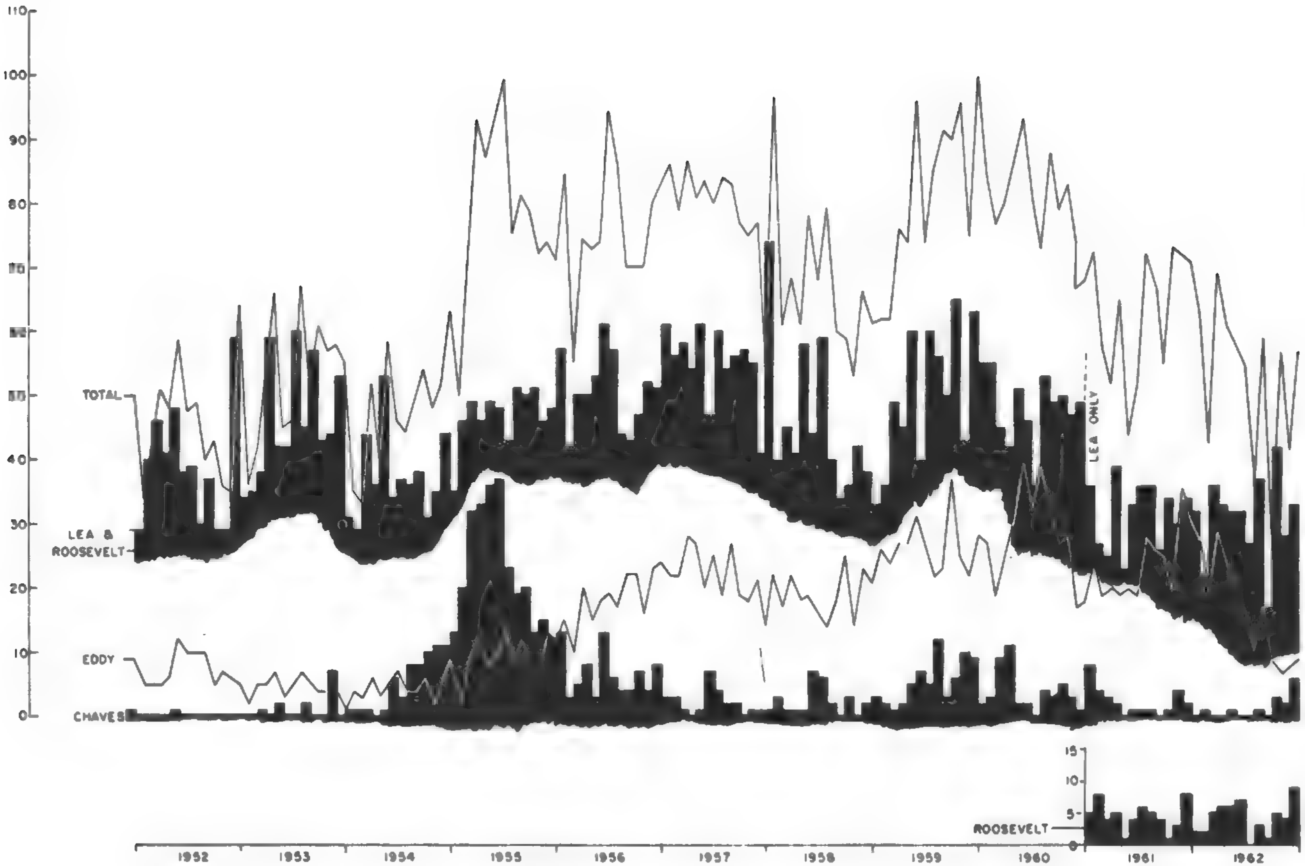

FIGURE 21.—Oil well completions by counties in southeastern New Mexico.

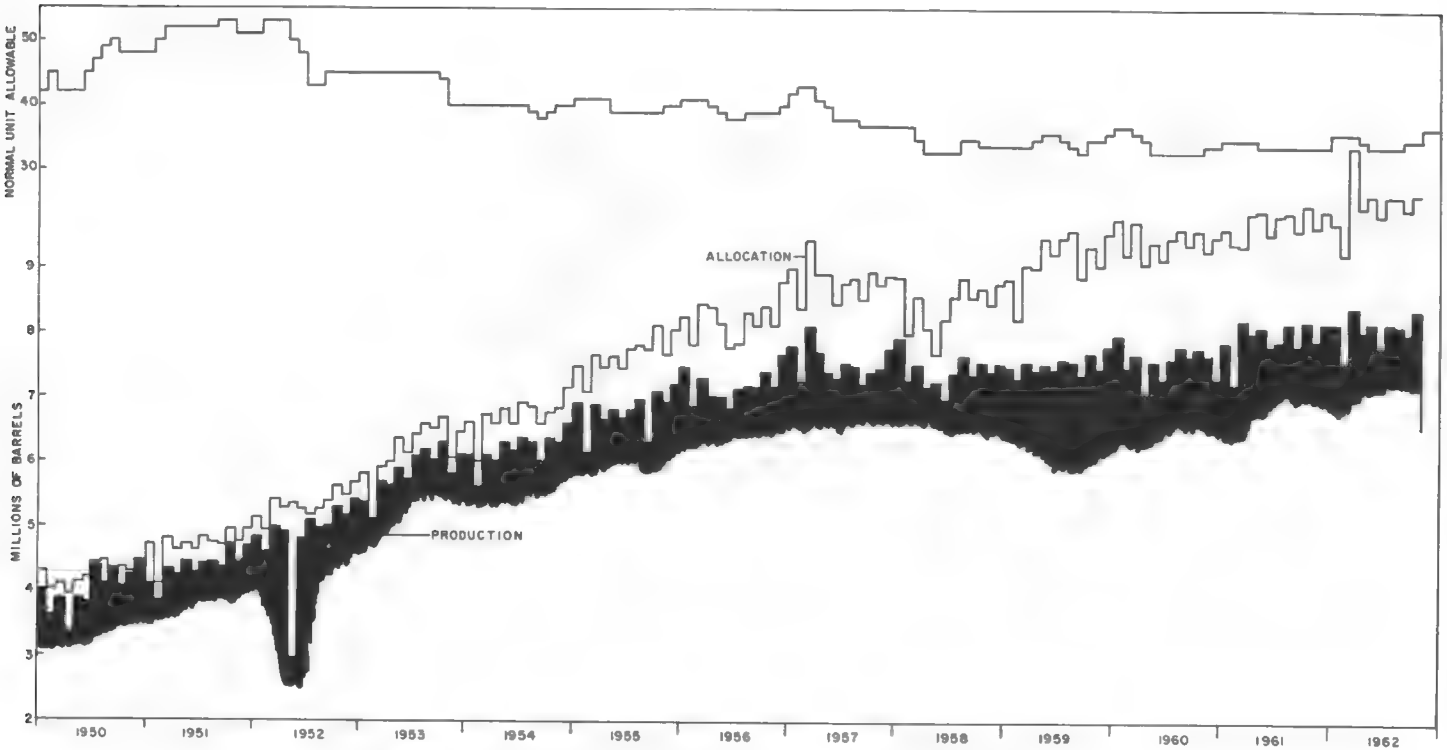

FIGURE 22.—Oil allocation and production in southeastern New Mexico.

TABLE 10.—*Largest producing fields in southeastern New Mexico*

CUMULATIVE PRODUCTION TO JAN. 1, 1964

Rank	Pools	Cumulative oil production (in barrels)
1	Eunice-Monument Grayburg-San Andres	266, 437, 051
2	Hobbs San Andres-Grayburg	176, 702, 538
3	Vacuum Grayburg-San Andres	101, 394, 407
4	Denton Devonian	68, 744, 627
5	Langlie-Mattix 7 Rivers-Queen	62, 109, 696
6	Drinkard	54, 119, 282
7	Jalmat Yates-7 Rivers-Tansill	53, 120, 659
8	Eumont Yates-7 Rivers-Queen	51, 943, 951
9	Grayburg Jackson Queen-Grayburg-San Andres	49, 567, 384
10	Gladiola Devonian	41, 782, 939
	1963 PRODUCTION	
1	Empire Abo	5, 712, 236
2	Caprock Queen	4, 918, 840
3	Vacuum Abo Reef	4, 235, 946
4	Denton Devonian	3, 789, 305
5	Monument Grayburg-San Andres	3, 407, 057
6	Hobbs San Andres	3, 361, 865
7	Vacuum Grayburg-San Andres	3, 322, 058
8	Gladiola Devonian	3, 181, 347
9	Loco Hills Grayburg-San Andres	2, 442, 129
10	Langlie Mattix 7 Rivers-Queen	1, 742, 95

On January 1, 1964, 14,916 wells were producing oil in southeastern New Mexico from 429 separate oilfields, as shown in the table below.

County	Number of wells	Production 1963	Cumulative production in barrels, Jan. 1, 1964
OIL PRODUCTION BARRELS			
Chaves	763	5, 209, 946	41, 457, 785
Eddy	3, 916	15, 414, 494	164, 887, 161
Lea	10, 032	75, 168, 087	1, 511, 994, 777
Roosevelt	205	3, 002, 466	14, 127, 501
Total	14, 916	98, 794, 993	1, 732, 467, 224
CASINGHEAD GAS PRODUCTION MCF			
Chaves		1, 128, 476	
Eddy		20, 367, 116	
Lea		240, 495, 791	
Roosevelt		10, 564, 993	
Total		272, 556, 376	
DRY GAS PRODUCTION MCF			
Chaves	6	1, 103, 668	2, 067, 130
Eddy	85	12, 334, 371	78, 212, 802
Lea	1, 321	158, 382, 218	2, 252, 779, 641
Roosevelt	2	111, 875	197, 972
Total	2, 816	171, 932, 132	2, 333, 257, 545

This brief history of development indicates the evolutionary process that southeastern New Mexico has experienced in gaining its present stature as a major oil producing area. This evolution depended on many factors : Accidental discovery in the period 1909 to 1920, the scientific utilization of geology in searching for anticlines during the 1920's; and the adoption of geophysical methods in the 1930's. During the 1950's a fuller utilization of engineering was needed to develop equipment for deeper exploration and to improve secondary recovery technique.

SUMMARY

Southeastern New Mexico is now a well-established oil- and as-producing area connected by pipeline to many parts of the Nation, including California, Washington, Minnesota, Iowa, Illinois, and ports on the Gulf of Mexico.

The basic geology of the area is well known; however, large areas are as yet untested. With few exceptions, exploration in this area is still based on the search for anticlinal structures; efforts to locate stratigraphic traps have not yet assumed major importance. However, stratigraphic exploration in New Mexico will undoubtedly lead to the discovery of major fields.

Although New Mexico produces far in excess of its own requirements for oil, most of the crude oil is transported from the State for refining and finished products returned. New Mexico, far richer than most States in energy resources, has not yet successfully built the manufacturing industries that utilize inexpensive energy or industries that utilize hydrocarbons as raw materials.

OUTLOOK FOR THE FUTURE

The Permian basin of New Mexico and Texas produces 25 percent of the Nation's oil and New Mexico contains a substantial part of this basin.

New Mexico will continue in the future as it has for the past 38 years to be one of the most actively explored areas in the Nation. Although some of the area is complex, in general the geologic, engineering, distribution, and marketing problems are simple as compared with other places.

The paucity of processing plants for the utilization of these vast volumes of energy and raw materials within New Mexico has resulted from many factors. These include an excellent export system, federal regulatory practices which do not encourage local utilization of natural gas, and probably a lack of appreciation of the marketing opportunities that New Mexico offers today compared to 38 years ago when the pattern for many of these factors was being set.

GEOLOGY AND OIL AND GAS PRODUCTION IN NORTHWESTERN NEW MEXICO

(By E. C. Arnold, New Mexico Oil Conservation Commission, Aztec, N. Mex.)

GEOLOGY

The San Juan Basin is mostly in San Juan, Rio Arriba, McKinley, and Sandoval Counties in northwestern New Mexico and encompasses an area of 15 to 20 thousand square miles. At present these are the only counties in this part of the State in which oil and gas have been discovered in commercial quantities.

The San Juan Basin is in the Navajo section of the Colorado Plateau physiographic province. The oil and gas fields of this part of New Mexico are shown on figure 23.

The San Juan Basin is bounded by a series of diverse structural and topographic features: on the northwest by a low structural platform on which are located several laccolithic mountains including the Carrizo Mountains of Arizona and the Ute and La Plata Mountains of Colorado; on the north by the San Juan Mountains of Colorado; on the northeast by a series of low structural arches which incompletely separate the basin from the Chama embayment; on the east by the Nacimiento and San Pedro uplifts. To the southeast the basin terminates along the highly fractured fault belt that marks the Rio Grande fault trough and to the south the Zuni uplift, the Mount Taylor syncline and the Acoma embayment mark the structural boundary. On the southwest the Zuni embayment is connected with the basin proper between the west end of the Zuni uplift and the south end of the Defiance uplift. On the west, the boundary is the long north-trending Defiance uplift which separates the San Juan Basin from the Black Mesa basin of Arizona.

The rocks which crop out in the area are shown on the geologic map (fig. 6). The generalized tectonic map (fig. 7) shows the regional structural framework of the area and the various structural elements which are present are shown on figure 24.

The names of the principal geologic formations present in northwestern New Mexico appear in table 1.

STRATIGRAPHY AND GEOLOGIC HISTORY

In its deepest part, sedimentary rocks are more than 15,000 feet thick in the San Juan Basin. Rocks from each of the geologic eras are represented in the outcrops or subsurface of the Basin. Also rocks of each system of the Paleozoic and Mesozoic Eras are present with the exception of the Ordovician and Silurian Systems. It is possible that strata belonging to those systems were deposited, but if so they were eroded prior to deposition of Upper Devonian strata.

Precambrian rocks.—Precambrian igneous and metamorphic rocks crop out in some of the uplifts that bound the San Juan Basin.

Cambrian rocks.—During Cambrian time northwestern New Mexico was a stable shelf area bordering the Cordilleran geosyncline to the west. Cambrian sediments deposited in the area that is now the San Juan Basin are represented by the Upper Cambrian Ignacio Quartzite which attains thicknesses up to 200 feet but is usually much thinner.

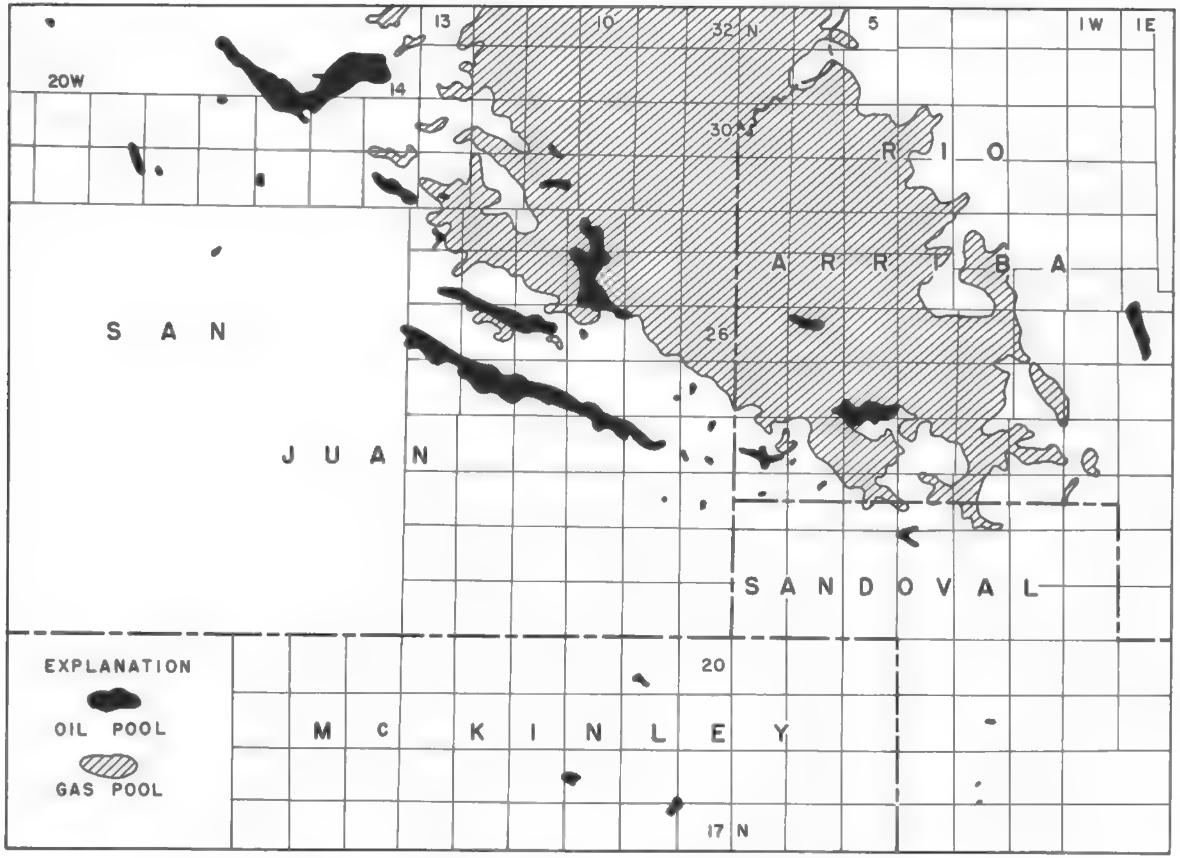

FIGURE 23.—Oil and gas pools in northwestern New Mexico.

Devonian and Mississippian rocks.—The Elbert Formation of Late Devonian age disconformably overlies the Ignacio Quartzite and in places rests directly upon Precambrian rocks. The Elbert Formation consists of a series of calcareous shale, quartzose sandstone, and thin limestone beds and marks the transgression of Devonian seas into the area. Northwestern New Mexico was still a shelf area bordering a

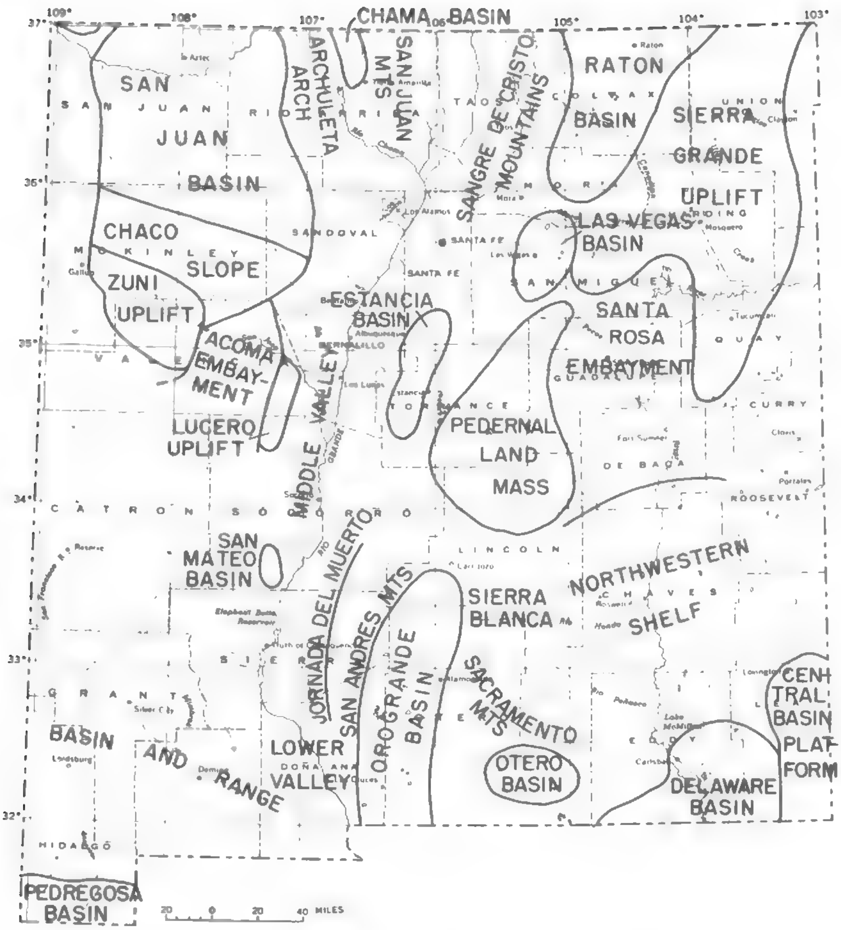

Figure 24.—Generalized structural map of New Mexico.

much deeper depositional basin to the north and west which accounts for the relatively thin strata deposited. The Elbert is not present in the southern part of the San Juan Basin. It is possible that its distribution may have been controlled by the central New Mexico positive area (Beaumont and Read, 1950, p. 49). Following deposition of the Elbert Formation, the Ouray Limestone was deposited. This

formation, which reaches a thickness of 75 feet, is continuously present in the northern part of the Basin but, like the Elbert, is absent to the south over the central New Mexico positive area.

The Leadville Limestone of Early and Late Mississippian age disconformably overlies the Ouray Limestone. It ranges up to 300 feet in thickness but is confined to the northern part of the San Juan Basin. Oil and gas have been produced from the Leadville in the Table Mesa and Hogback fields.

Pennsylvanian, rocks.—A period of emergence and erosion occurred in the San Juan Basin area subsequent to deposition of the Mississippian Leadville Limestone. Earlier Paleozoic formations wherever exposed were subjected to long-continuing subaerial erosion. Following this erosion, Pennsylvanian seas transgressed across the area and covered all except two positive areas, the Zuni and Defiance uplifts.

The Molas Formation is the basal unit of the Pennsylvanian, ranges in thickness from 60 to 200 feet, and consists of red, green, and gray shale, red sandstone, and cherty limestone.

Immediately following the transgression of Pennsylvanian seas across the area the Uncompahgre fold belt came into existence in southwestern Colorado. This positive area was one of the ranges of the Ancestral Rocky Mountains and elastic material eroded from it was deposited, in association with marine limestone, to form the Hermosa Formation. Northwest of the area occupied by the San Juan Basin a deep basin along the margin of the Uncompahgre axis was apparently characterized by a complete lack of aerating currents and was the site of accumulation of fetid shales and precipitates (Beaumont and Read, 1950, p. 50). These strata represent the Paradox Member and interfinger with elastic and limestone beds of the Hermosa Formation to the southwest. The Paradox Member is thus restricted to northern San Juan County and is an evaporitic facies in the Hermosa. The Hermosa Formation ranges up to 2,000 feet thick in the northwestern part of the San Juan Basin but thins and is more elastic to the south and east. The Paradox Member of the Hermosa Formation is an important reservoir for oil and gas in the Four Corners area and recent discoveries at Rattlesnake, Paj arito, Table Mesa, and Tocito dome have caused optimism regarding future possibilities in the San Juan Basin. The major portion of the basin remains largely unexplored in these deeper zones but undoubtedly will receive increasing attention in the future.

During Late Pennsylvanian time deposition of elastic sediments appears to have exceeded subsidence of the marine basin. This resulted in the deposition of red shale, sandstone, and arkose of the Pennsylvanian and Permian Rico Formation which is transitional into the Cutler Formation of Permian age.

Permian rocks.—Clastic sedimentation continued into Permian time, particularly in the northern part of the San Juan Basin and locally up to 2,000 feet of coarse red and brown arkose of the Cutler Formation was deposited. Encroachment of Permian seas from the south resulted in deposition in the southern part of the basin of a series of basal elastics succeeded by evaporites, fine-grained sandstones, and siltstones represented by the Abo, Yeso. Glorieta, and San Andres Formations which attain an aggregate thickness of 1,400 feet.

Triassic and Jurassic rocks.—During Early Triassic time the Moenkopi Formation was widely deposited west of the San Juan Basin,

but it is very thin or absent over most of the basin. During Late Triassic time fluviatile sediments of the Chinle Formation were widely deposited across the area. The basal beds in this sequence are the Shinarump Conglomerate or the Agua Zarca Sandstone Member. Overlying the coarse beds are red and variegated shales up to 1,500 feet thick. Sources of these materials were the surrounding upland areas of the Ancestral Rocky Mountains. Uppermost Triassic rocks in the San Juan Basin are represented by the Wingate Sandstone of the Glen Canyon Group. The Wingate is more than 700 feet thick in the Four Corners area but it thins to the east and is absent on the east side of the basin. It consists of red sandstone and siltstone. Immediately following deposition of the Glen Canyon Group and prior to San Rafael time the Ancestral Rocky Mountains were rejuvenated and the area that received Jurassic sediments was locally folded and eroded (Beaumont and Read, 1950). Sediments of the San Rafael Group were deposited on this surface under alternating shallow marine and littoral conditions. In northwest New Mexico the San Rafael Group includes the Entrada, Todilto, Summerville, and Bluff Formations and this group attains a thickness of about 300 feet in the San Juan Basin. Uppermost Jurassic rocks are the fluviatile deposits of the Morrison Formation which reaches a thickness of 800 feet.

Cretaceous rocks.—Lower Cretaceous strata are thin and in many places absent in the San Juan Basin. The basal unit is the Dakota Sandstone of Early and Late Cretaceous age, which ranges in thickness from 100 to 300 feet and is a complex series of interbedded and interfingering sandstone and shale units.

Thick calcareous muds of the Mancos Shale were deposited on the Dakota throughout the Basin. At this time, to the west and southwest of the present San Juan Basin, rising mountains shed debris that was deposited into the Basin. There followed a series of regressions and transgressions of the Cretaceous sea which characterized Cretaceous sedimentation in the San Juan Basin and which resulted in the deposition of a series of interfingered sandstone and shale units. Many of the sandstone units represent shoreline (strandline) deposits or offshore sandbars, many of which now form petroleum reservoirs_

During early regressions, the Juana Lopez Member of the Mancos Shale and the Gallup Sandstone were deposited. The Gallup strandline occupied a position just southwest of the present Bisti-Gallup oilfield, the oil occurring in a series of offshore sandbars. These sand bodies are completely encased in impermeable Mancos Shale and this accounts for entrapment of the oil. Other oilfields that produce from the Gallup, all of which are long and narrow and trend northwestward, occur along the central part of the basin and are similar in origin to Bisti. These include Otero, Lybrook, Escrito, Devils Fork, Angels Peak, Kutz, Gallegos, Lotah, Cha Cha, South Waterflow, and Horsehoe Canyon. Other regressive-transgressive cycles of shorter duration deposited sandstone units in the southern part of the basin.

The Point Lookout Sandstone represents the first regression that completely traversed the basin area as it is presently defined. Although lateral variations in thickness, grain size, and degree of sorting are common in the Point Lookout Sandstone, it is a remarkably

continuous unit throughout the basin. The Point Lookout varies in thickness from 70 to 400 feet. In general it is thicker in the southern and western parts of the basin and thins and becomes finer grained to the north and east. In places individual massive sandstone bodies within the formation are continuous over an area of several square miles. In other places there is abrupt lensing and interfingering of sandstone and shale.

The swampy, lagoonal environment created as the sea receded brought about the accumulation of the Menefee Formation which is composed of thin, irregular, lenticular sandstone beds, organic shale and coal. The Menefee is thicker toward the source area to the southwest; its partial equivalent, the Crevasse Canyon Formation, is as much as 1,600 feet thick in that part of the basin.

The Cliff House Sandstone is the uppermost transgressive marine sandstone in the Mesaverde Group. It is transitional between the overlying Lewis Shale and the underlying Menefee Formation and is characterized by large-scale intertonguing with the Lewis Shale. In the northern and eastern parts of the basin the Cliff House is virtually absent, being represented only by silty fine-grained thin-bedded sandstone whereas it locally attains a thickness of about 1,000 feet in the southwestern part of the basin. Gas has been produced from several sandstone tongues in the Lewis Shale.

The Lewis Shale overlies the Mesaverde Group and underlies the Pictured Cliffs Sandstone. It is characterized by intertonguing with both the Pictured Cliffs and Cliff House and by thinning from northeast to southwest. In the extreme notheastern part of the basin it is more than 2,000 feet thick, in the central part of the Blanco Mesaverde Pool it is about 1,650 feet thick, and it wedges out about 50 miles southwest of Aztec. The Lewis is a dark-gray shale that is generally more siliceous and less calcareous than the Mancos.

The Pictured Cliffs Sandstone is the uppermost wholly marine lithologic unit in the San Juan Basin and represents the final retreat of the Cretaceous sea from the area. This formation rises stratigraphically from southwest to northeast. Permeability trends in the Pictured Cliffs, which extend from southeast to northwest, undoubtedly roughly parallel old shorelines. These permeability trends are related to the rate of regression at a given time; during long periods of stability cleaner, better sorted sands were deposited due to long continued wave and current action while during periods of rapid regression shale, silt, and sand particles were deposited together, with little opportunity for reworking or sorting. This accounts for the long, relatively narrow permeability trends separated by impermeable beds trending the same direction, which the Pictured Cliffs Sandstone exhibits. This is also the controlling factor in the occurrence of natural gas in this formation. The Pictured Cliffs is absent in the outcrop in the east-central part of the basin but reaches thicknesses in excess of 350 feet in the western part of the basin.

Conformably overlying the Pictured Cliffs is the Fruitland Formation, which in turn is conformably overlain by the Kirtland Shale. The lower part of the Fruitland is composed of black carbonaceous shale, lenticular silty sandstone, and coal. Its depositional environment was characterized by broad low-lying flood plains and widespread swamp conditions with heavy vegetation. Late in Fruitland

time and continuing through Kirtland time it is evident that a new source area developed to the northwest, probably from early orogenic movements of the Laramide revolution. A depositional basin apparently developed in the northwestern part of the area during this time into which were poured the sands and clays which form the Kirtland Shale and the Farmington Sandstone Member of the Kirtland. The Kirtland and Fruitland Formations combined are in excess of 1,650 feet thick in the northwestern part of the area but are thinner to the southeast.

Upper Cretaceous and lower Tertiary rocks.—As mountain building of the Laramide orogeny proceeded the clastics which form the Ojo Alamo (Upper Cretaceous), Nacimiento (Paleocene), Animas (Upper Cretaceous and Paleocene), and San Jose (Eocene) Formations were deposited under the flood plain and fluviatile conditions. In the eastern part of the basin these beds attain a thickness of nearly 4,000 feet. To the west this section thins and it has been completely removed by erosion in the southwestern half of the basin. During Late Cretaceous and early Tertiary time the structure of the present basin began to form.

OIL AND GAS PRODUCTION

Most of the oil and gas that has been produced in northwestern New Mexico has come from reservoirs in the Pennsylvanian and Cretaceous Systems; the majority has come from the Cretaceous. Small amounts of oil and gas have been produced from the Leadville Limestone (Mississippian) at Hogback and Table Mesa. At the Media Pool in Sandoval County the Entrada Sandstone (Jurassic) produced 18,218 barrels of oil prior to depletion. Tables 11 and 12 summarize gas and oil production in northwestern New Mexico.

TABLE 11.—*Accumulative dry gas and condensate production by stratigraphic unit to Jan. 1, 1964, in northwestern New Mexico*

Producing zone	Pool	Number of wells, January 1, 1964	Gas, MCF	Condensate, Bbls.
Pennsylvanian	Barker Creek	9	100,446,933	63,150
	Blue Hill	1	1,221,724	
	Rattlesnake	[illegible]	114,284	1,906
	Undesignated	2	2,533,430	49,949
Total		14	104,316,371	115,007
Dakota	Basin	1,029	316,045,866	4,534,251
	Barker Creek	12	13,306,222	
	Ute dome	6	3,215,438	2,830
Total		1,048	332,567,526	4,537,081
Greenhorn	Undesignated	1	201,909	1,919
Total		1	201,909	1,919
Gallup	Largo	3	907,948	10,343
	Undesignated	2	5,729,848	70,640
Total		5	6,637,796	80,983
Mesaverde	Blanco	1,964	1,628,274,359	5,316,429
	Flora Vista	12	4,678,700	37,479
	Twin Mounds	0	652,995	4,575
	Undesignated	5	2,004,435	10,612
Total		1,981	1,635,610,489	5,369,100
Chacra	Otero	35	9,834,137	3,154
	Undesignated	6	1,365,977	55
Total		41	11,300,114	3,209
Pictured Cliffs	Aztec	383	99,123,820	2,375
	Ballard	437	126,683,234	27,676
	Blanco	56	22,447,923	4,709
	Blanco, East	21	6,078,717	207
	Blanco, South	1,089	316,711,807	37,850
	Choza Mesa	17	1,521,121	
	Fulcher Kutz	319	131,197,926	2,836
	Gavilan	80	16,354,070	44,281
	Kutz West	209	77,503,420	210
	Tapacito	151	71,878,989	26,662
	Undesignated	8	2,412,211	108
Total		2,770	871,913,238	146,914
Fruitland	Aztec	32	5,605,107	2,114
	Aztec, North	0	15,138	
	Flora Vista	5	630,609	
	Gallegos	1	616,376	13
	Kutz	4	1,843,948	912
	Kutz, West	2	248,672	
	Los Pinos, North	1	220,364	
	Los Pinos, South	1	315,611	
	Undesignated	3	313,686	
Total		49	9,809,511	3,039
Farmington	Kutz	3	193,234	
	Undesignated	6	460,009	1,933
Total		9	653,243	1,933
Grand total		5,918	2,973,010,197	10,259,185

TABLE 12.—*Accumulative oil production by stratigraphic unit to Jan. 1, 1964, northwestern New Mexico (from NMOCC official records)*

Producing zone	Pool	Number of wells, Jan. 1, 1964	Oil, barrels
Pennsylvanian	Four Corners	1	79, 724
	Hogback	2	368, 595
	Rattlesnake	8	277, 096
	Undesignated	1	36, 738
Total		12	762, 153
Entrada	Media	0	18, 218
Total		0	18, 218
Dakota	Hogback	10	3, 710, 627
	Lindrith	1	27, 141
	Rattlesnake	42	4, 672, 012
	Salt Creek	4	42, 577
	Table Mesa	13	1, 220, 353
	Undesignated	12	228, 181
Total		82	9, 900, 891
Mancos	Boulder	25	769, 945
	Puerto Chiquito	26	287, 117
	Undesignated	2	21, 500
Total		53	1, 078, 562
Sanastee	Otero	0	29, 882
Total		0	29, 882
Tocito	Blanco	22	3, 553, 158
Total		22	3, 553, 158
Gallup	Angels Peak	22	371, 968
	Bisti	404	26, 100, 540
	Cha Cha	98	4, 877, 348
	Devils Fork	40	707, 840
	Escrito	48	1, 284, 407
	Gallegos	99	1, 227, 012
	Horseshoe	383	15, 784, 491
	Hospah	48	4, 323, 962
	Kutz	1[illegible]	448, 191
	La Plata	1	153, 732
	Lybrook	10	126, 056
	Many Rocks	55	483, 572
	Mesa	12	100, 279
	Otero	47	1, 105, 017
	Shiprock	39	47, 990
	Simpson	6	346, 936
	Totah	70	2, 506, 597
	Verde	168	6, 861, 779
	Waterflow, South	2	8, 586
	Undesignated	80	952, 858
Total		1, 646	67, 819, 160
Mesaverde	Chaco Wash	7	3, 431
	Otero-Point Lookout	0	18, 881
	Red Mountain	31	138, 011
	San Luis	7	35, 817
	Undesignated	8	6, 724
Total		53	202, 864
Pictured Cliff's	Undesignated	3	49, 952
Total		3	49, 952
Farmington	Bloomfield	4	3, 302
	Oswell	2	9, 545
	Undesignated	1	1, 107
Total		7	13, 954
Grand total		1, 878	83, 428, 794

PENNSYLVANIAN PRODUCTION [1]

Production from Pennsylvanian rocks has come from several separate zones in the Paradox Member of the Hermosa Formation. Total production from Pennsylvanian rocks has been 104,316,371 MCF of dry gas from structural traps on the west side of the basin. Of this total, 100,446,933 MCF has come from Barker Creek dome. Oil has been produced from Pennsylvanian rocks at Hogback, Rattlesnake, Pajarito and Tocito domes and from north of Shiprock. Total oil production from the Paradox Member through 1963 was 762,153 barrels. An important discovery was made in the Paradox at Tocito dome during 1964. Although structural control seems to be evident in the accumulation of several pools in the San Juan Basin, there are indications that stratigraphic traps are also important (Wengerd, Oil and Gas Journal, 1956). Future discoveries may be made, therefore, which have little or no relationship to geologic structure. In fact, there is evidence that Laramide folding and faulting may have, in some areas, destroyed earlier oil and gas accumulations. Undoubtedly much additional exploration in Pennsylvanian rocks will occur in the future.

CRETACEOUS PRODUCTION

Oil and natural gas have been encountered over wide areas in rocks of Cretaceous age and in many separate zones. In ascending order the gas-producing zones are the : Dakota, Graneros, Greenhorn, Sanastee, Gallup, Point Lookout, Menefee, Cliff House, Chacra (now Cliff House of some authors), Pictured Cliffs, Fruitland, and Farmington. The major producing zones are those of the Dakota, Point Lookout, Cliff House, and Pictured Cliffs. Table 11 is a summary of natural gas production showing production by pools, with formation totals. Oil producing zones of the Cretaceous include the: Dakota, Graneros, Greenhorn, Sanastee, Gallup, Mancos, Mesaverde, Pictured Cliffs, and Farmington. Reservoirs in the "Dakota" and "Gallup" are the major producers. Table 12 is a summary of oil production from the area by pool and producing unit.

"Dakota producing interval".—The vertical limits of the "Dakota producing interval" for development and proration purposes are defined by the Commission as a section beginning at the base of the Greenhorn Limestone Member of the Mancos Shale and continuing downward 400 feet into the Dakota Sandstone. This also includes the Graneros Shale Member of the Mancos. "Dakota" gas is produced from two structural traps : Barker Creek dome and Ute dome. The major source of "Dakota" gas, however, is a huge stratigraphic reservoir which encompasses approximately one-seventh of the total area of the San Juan Basin. Because of the administrative difficulties involved in defining pool boundaries the New Mexico Oil Conservation Commission has defined the Basin Dakota pool as being that area in San Juan, Rio Arriba, and Sandoval Counties that produces gas from the "Dakota" with the exception of older "Dakota" structures that are obviously separate. The semi-proven productive area of this pool approximates 1,400,000 acres and is an elongate area in the cen-

[1] The boundaries of some of the named zones discussed in the following part of the text were chosen for economic reasons, and may not be the same boundaries as those used for named stratigraphic units by the U.S. Geological Survey.

tral part of the basin about 80 miles long from northwest to southeast and 50 miles wide from southwest to northeast near the center of the pool. At the beginning of 1964, 1,029 wells were producing in this pool, with 350,967 acres dedicated to these wells on 320-acre spacing. The pool is less than one-third developed at this time. Producing depths range from 5,000 to 8,000 feet within the Basin Dakota pool.

On the basis of petrographic analysis of "Dakota" cores, Burton (1955) concluded that the direction of "Dakota" deposition in the northern part of the basin was from the north. Toward the southwest edge of the pool the percentage of clay minerals increases, reducing effective permeability. This permeability barrier provides an effective seal. Production has been confined to an area south and southwest of the axis of the basin (Burton, 1955) .

- Most of the oil produced from the "Dakota" comes from small structures on the west side of the basin at Rattlesnake, Hogback, and Table Mesa. Some oil accumulations in stratigraphic traps have been encountered in the Basin Dakota gas pool. Sandstone beds in the Graneros Shale Member contribute most of this oil.

"Gallup zones".—The "Gallup zones" have been the major oil producers discovered to date in the Mancos Shale. Production comes from sandbar-type stratigraphic traps and from fractured zones in the Mancos Shale along the Hogback on the northwest side and the eastern rim of the Basin. Table 12 shows that 67,428,160 barrels have been produced from the "Gallup zones" out of an accumulative total production of 83,428,794 barrels from all formations. Some zones have proven to be predominantly productive of gas, but the "Gallup" is not considered to be a source of significant gas reserves. Net thickness of effective pay zones varies from 5 to 30 feet in the sandstone in the "Gallup".

"Mesaverde zone."—Minor amounts of natural gas have been produced from isolated small structural or stratigraphic traps in part of the Mesaverde Group, such as at Twin Mounds and Flora Vista fields. The major source of gas is another huge stratigraphic reservoir which is about 70 miles long and 40 miles wide at the widest point. Much of the area underlain by the Basin Dakota gas pool is also occupied by the Blanco Mesaverde pool. The eastern and northern extremities of each pool occupy approximately the same position, but "Dakota" production extends from 10 to 18 miles west and southwest of the Blanco Mesaverde pool boundary. The northwest boundary of the two reservoirs occupies about the same position but "Dakota" production extends about 10 miles beyond the southeastern extremity of the Blanco Mesaverde pool. Approximately 922,000 acres are within the limits of the Blanco Mesaverde pool as defined by the New Mexico Oil Conservation Commission. At the beginning of 1964 there were 1,964 wells producing in the pool spaced on 320-acre units. Total acreage presently dedicated to producing wells is 609,197 acres. The pool is therefore about two-thirds developed and it is not likely that its present boundaries will be extended significantly. Producing depths range from 4,000 to 6,500 feet within the pool. At the time of gas accumulation in the Blanco Mesaverde pool, the southwest part of the basin apparently was depressed with respect to the northeast part. While the strata were inclined, gas moved by buoyant separation to the sealed up-dip ends of porosity wedges (Silver, 1950). The present

structure of the basin is therefore not related to gas accumulation in the "Mesaverde" reservoir.

Minor amounts of oil have been produced from the upper part of Mesaverde Group, mostly from sandstone lenses in the Menefee Formation.

"Pictured Cliffs zone."—The third major gas-producing zone in the Cretaceous System occurs within the Pictured Cliffs Sandstone. Production characteristics differ from the "Dakota" and "Mesaverde" in that production is confined to permeability trends which in many cases are not more than 1 or 2 miles wide, although in some areas widths reach 6 or 7 miles. These productive trends are aligned from northwest to southeast and are separated, sometimes imperfectly, by beds in which effective permeability is reduced by shale and silt deposited with the sand. This zone ranges in depth from 1,000 to 4,000 feet within the producing area. As of January 1, 1964 there were 2,770 wells producing from 11 separate pools in this formation. Accumulative production through 1963 was 871,913,238 MCF. Present total proven productive area, based on assignment of 160 acres to each well, is 392,715 acres. Commercial production is indicated from at least an additional 80,000 acres in the Pictured Cliffs.

"Chacra, Fruitland, and Farmington zones."—Minor amounts of gas are produced from the "Chacra and Fruitland zones." The "Chacra" is productive at Otero in Rio Arriba County and from a few wells in eastern San Juan County. Most of the "Fruitland" production has come from isolated sandstone beds in the Aztec-Bloomfield area. The Farmington Sandstone Member of the Kirtland Shale is productive of both oil and gas, also mainly in the Aztec-Bloomfield area, but production rates and reserves are very low due to the extreme lenticularity of productive sandstone beds.

OIL AND GAS EXPLORATION IN OTHER PARTS OF NEW MEXICO

(By D. S. Nutter, New Mexico Oil Conservation Commission, Santa Fe, N. Mex.)

While all production to date has been from the previously discussed eight counties of northwestern and southeastern New Mexico, there have been encouraging reports of possible oil or gas structures and shows of oil and gas in various other parts of the State. Surface and subsurface geology indicate the presence of several major structural features (fig. 24) that have not been adequately tested for oil and gas.

The Chama basin lies directly east of the San Juan Basin and is separated from it, by the Archuleta arch ; it is bordered on the east by the San Juan Mountains. A few shallow wells have been drilled in the Chama basin and shows of gas have been reported. None of these wells, however, has been completed as a producing well.

The Raton Basin is between the Sangre de Cristo Mountains and the Sierra Grande uplift. Potentially oil-bearing rocks ranging in age from Pennsylvanian through Cretaceous are present. Several major companies have conducted limited drilling programs in the Raton Basin and have reported shows of oil. Lack of appreciable folding within the Raton Basin, however, reduces the possibility of structural entrapments. It is believed that the better prospects for the dis-

covery of oil or gas are in stratigraphic traps on the east and west flanks of the basin where the lower beds wedge out against the Precambrian uplifts.

The Sierra Grande uplift, which lies east of the Raton Basin, was uplifted during Pennsylvanian time. Prospects for oil and gas associated with it are limited to Permian or younger rocks.

West of the Sierra Grande uplift, and separated from the Raton Basin on the north by a narrow belt of volcanic rocks, is the Las Vegas Basin. It is bounded on the west by the Sangre de Cristo Mountains. Several wells have been drilled in the Las Vegas Basin; perhaps the most significant of these is a well drilled in 1960 from which 100,000 cubic feet of gas per day was reported. Analysis of the gas indicated 98.69 percent methane. This production was reported to be at depths from 4,649 feet to 4,791 feet in rocks of Pennsylvanian age. After extensive acidizing and fracture treatment, the well was abandoned. Sedimentary rocks up to 5,000 feet thick have been reported in the Las Vegas Basin. Although the Cretaceous beds may prove productive, it is believed that the greatest potential in this basin is in rocks of Pennsylvanian age.

East of the Sierra Grande uplift, small parts of the Dalhart and Palo Duro basins extend from Texas into New Mexico. There has been little activity in either of these areas and more extensive exploration is justified.

The Tucumcari basin, referred to as the Santa Rosa embayment on figure 24, is encompassed by the Sierra Grande uplift on the east and north, the Pedernal landmass on the west, and the Northwestern shelf on the south. Several relatively deep wells have been drilled in this area in the last few years, some with encouraging shows, but no production has yet been found. Almost 10,000 feet of sediments are present in this basin, which includes an area of over 4,000 square miles. It has not yet been adequately tested.

West of the Pedernal landmass and east of the Sandia uplift lies the Estancia basin. This long, narrow basin extends from southern Santa Fe County through western Torrance County and underlies the Estancia Valley, a broad topographic basin. The deep basinal character of the Estancia basin is demonstrated by test wells which have been drilled in the area. One well, located 9 miles from the nearest outcrop of Precambrian rocks in the Pedernal Hills, penetrated more than 5,900 feet of sedimentary beds before encountering Precambrian schist. Several wells that have been drilled on anticlinal folds in the basin have encountered shows of oil, as have some which were drilled on the west flank of the basin near the Manzano Mountains and at the base of the east slope of the Sandia Mountains.

To the west of the Rio Grande Valley, lying between the Lucero uplift on the east and the Zuni uplift on the west, is the Acoma embayment. Marine sedimentary rocks up to 5,000 feet in thickness have been penetrated in wells drilled in the area. Although numerous anticlinal structures exist in the area, interest has lagged and exploratory wells have been few and widely scattered, due possibly to widely scattered volcanic necks. Basalt flows cover part of the area.

In the extreme southwest corner of New Mexico, the Pedregosa basin into nto the State from Mexico. Although only one well has been drilled in this basin, it penetrated a total depth of 14,585 feet. No shows were reported other than gas-cut drilling mud recovered on

a drillstem test from 4,190 to 4,219 feet in a limestone of Permian age.

The Orogrande basin in eastern Doiia Ana and western Otero Counties, occupies most of the area of the topographic Tularosa Valley. This basin is bounded on the west by the Oscura and San Andres Mountains and on the east by the Sacramento Mountains and the Sierra Blanca. Although the basin contains up to 7,000 feet of sedimentary rocks little exploratory work has been done and very little is likely to be done in the near future, inasmuch as the basin is now largely a U.S. military reservation.

The Otero basin, in southeast Otero County, may comprise an area of as much as 1,000 square miles. It is bordered by the Hueco Mountains on the west, the Guadalupe Mountains on the east, the Sacramento Mountains on the north, and the Cornudas Mountains on the south. Part of the area is within the boundary of the White Sands Missile Range. Few wells have been drilled in the area, the deepest of which bottomed at 4,646 feet in rocks of Pennsylvania age. The structure of the basin is not well known and its extent remains to be proven, although it is reported to include Paleozoic rocks equivalent to those found in the producing areas of southeast New Mexico.

Space does not permit the discussion of individual anticlines, domes, and other structural features within these areas, and other areas have not been mentioned at all. Among the latter are the Rowe basin, the San Mateo basin, the middle and lower Rio Grande Valleys, the Jornada del Muerto, and the Basin and Range country of Hidalgo, Luna, and Dofia Ana Counties.

COAL

(By F. E. Kottlowski, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex., and E. C. Beaumont, Albuquerque, N. Mex.)

The mining and distribution of coal is the second largest mineral industry in the United States in respect to dollar value of production. It is exceeded only by petroleum, and outranks all metallic minerals combined. Production of coal increased rapidly in the early 1800's in the Eastern States. Nationwide, it doubled almost every decade until about World War I when the Nation's early peak in production was reached during 1918. Coal production and consumption declined thereafter throughout the Nation, mainly because of the large expansion in the use of petroleum and natural gas and the depression of the 1930's. The impetus afforded by World War II, however, stimulated coal mining, so that shortly after the war in 1947 it reached an all time high of 688 million tons. Production declined in the postwar period and in 1963 totaled 452 million tons. This substantial tonnage was valued at about $2 billion, or about $4.46 per ton at the mine.

The United States coal production in 1963 accounted for about 21 percent of the total energy supply during the year (U.S. Bur. Mines, 1964). Consumption was divided into 51 percent used by electric power utilities, 19 percent by coke plants, 24 percent by other manufacturing and mining industries including a small part used by the transportation industries, and 6 percent delivered to retailers for sale as domestic fuel.

HISTORY OF COAL MINING IN NEW MEXICO

Coal mining became an important industrial activity in New Mexico about eight decades ago, but the prehistoric Indians wore "jet" ornaments, fragments of shiny coal, more than 12,000 years ago. Coal ash, dated at about 1300 A.D., has been found in long-cooled firepits of the Hopi Indians and in the abandoned pueblos in the San Juan River region. The Spanish used a small amount of coal several centuries ago in north-central New Mexico. Anthracite was mined near Madrid for local use as early as 1835. Mining on a significant scale began in 1861, when U.S. Army troops stationed at Fort Craig south of Socorro opened a mine in the Carthage coal field.

Annual Statewide production was measured in tens of tons until 1878-82, when railroads were built into Sand through New Mexico, providing transportation to out-of-state markets and creating a need for coal to fuel the steam locomotives. Thus in 1882, the first year in which accurate records were kept, 164,000 tons of coal were mined in the Territory, and coal became an important New Mexico product.

From the time of the first large-scale mining of coal in New Mexico, its main commercial users were railroads and smelters. As railroad lines spread over the Southwest in the early 1880's, trains ran from New Mexico westward to California and eastward into Texas on power generated from the State's coal. The smelters used large tonnages of coking coal, powdered bituminous coal, subbituminous coal, and much slack coal. The old-time lead blast furnaces used the coke, whereas the copper smelters used powdered bituminous coal. The subbituminous coal near Gallup was used, because of lower shipping charges, by smelters at Clarksdale, Hayden, Inspiration, Clifton, and Douglas in Arizona, and El Paso in Texas.

Early warnings of the switch by railroads from coal to oil came in 1911, with the beginning of use of oil-fired steam locomotives in California. The change from steam to diesel power started on a large scale after World War II, and was largely completed by the mid-1950's. Smelters also switched to oil in the 1910's and 1920's, and later to natural gas.

Around the turn of the century New Mexico coal was used on a large scale for space-heating of homes and offices. Coal for such use was shipped to Arizona and California, and to Texas, western Oklahoma, and western Kansas. The Arizona and California markets vanished in the early 1900's when oil and gas replaced coal for such purposes. The use in Texas, Oklahoma, and Kansas declined drastically after World War II. By the late 1950's fuel oil and natural gas had largely replaced coal for heating purposes even in the New Mexico coal-mining areas.

The peak year for coal mining in New Mexico was 1918 (fig. 25) when World War I stimulated coal mining. The more than 4 million tons of coal mined that year were used mainly in smelters, steel plants and other factories, and by the railroads. Even during the depression of the 1930's, the State's average annual production was close to 1.3 million tons. Dieselization and the use of natural gas caused a reduction to below the million-ton mark in 1950. With the opening of the new coking-coal mines in southern Colorado to serve the Pueblo steel mills, New Mexico production fell to only 123,099 tons in 1954, and to 116,656 tons in 1958.

Development of the Kaiser Steel Corp. coking-coal mines near Koehler in the Raton area aided the upward swing of coal mining in 1960. The big boom for coal production, however, has been the introduction of large-scale strip mining in McKinley and San Juan Counties (Kottlowski, 1964). The combination of inexpensive strippable coal and the increasing demand for electric power in Arizona and New Mexico has led to the opening of the McKinley strip mine by the Pittsburg and Midway Coal Co. near Gallup, and the Navajo strip mine

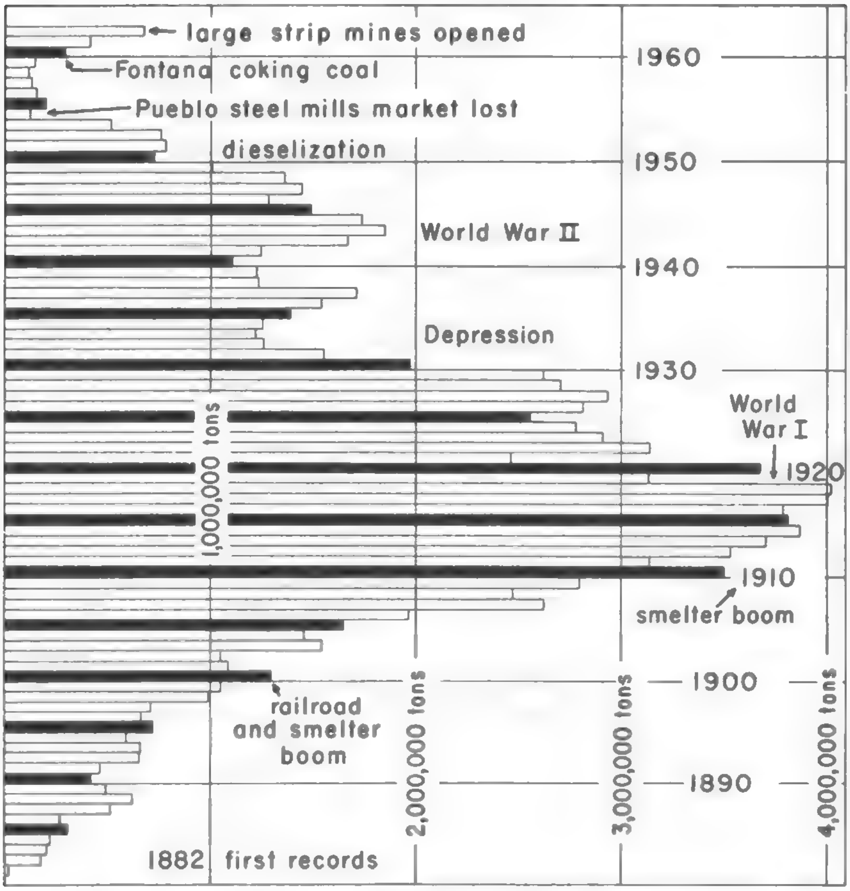

FIGURE 25.—Annual coal production in New Mexico, 1882–1962.

of the Utah Construction and Mining Co. near Fruitland. The McKinley mine supplies about 380,000 tons annually to the 110-megawatt Cholla steam-electric generating plant of the Arizona Public Service Co. at Joseph City, Ariz. The Navajo mine supplies about 800,000 tons annually to the 350-megawatt Four Corners powerplant of the Arizona Public Service Co. near Fruitland.

Future production prospects.—Future prospects are for increased coal mining. The Navajo strip mine production is scheduled to be increased to 2.5 million tons by 1975. The Public Service Co. of

New Mexico has acquired areas underlain by strippable coal adjoining the Navajo mine property northwest of Bisti Trading Post and north of Fruitland. The Public Service Co. plans to use this coal to generate electric power in the late 1960's. In addition, El Paso Natural Gas Co. has a large block of strippable coal under lease from the Navajo Indians, southeast of the Navajo strip mine, which may be used in a coal conversion plant. By 1966, the Kaiser Steel Corp. expects to open a new coking-coal mine in York Canyon about 35 miles west of Raton, its production replacing that of the Koehler mine.

New Mexico's coal production ranked 19th among coal-producing States during 1962 when only 677,000 tons were mined, and 9th among States west of the Mississippi River. With the large increase to 1,945,000 tons mined during 1963 (U.S. Bur. Mines, 1964) , New Mexico climbed to 15th in the Nation, and 6th in the West. During the late 1960's production in the State may increase to more than 4 million tons annually.

Coking coal.—Most of the coking coal in New Mexico is in the Raton field of Colfax County, and smaller amounts occur in the Carthage field of Socorro County and the Cerrillos field of Santa Fe County. These fields are discussed in more detail below.

Coke was first produced in New Mexico by the San Pedro Coal and Coke Co. from the Carthage field, and was used first to supply lead smelters in southwestern New Mexico, and later in El Paso and northern Mexico. Still later, the center of coking coal production shifted to the Raton field, from which large quantities were shipped from mines of the Stag Canon Fuel Co. and the St. Louis, Rocky Mountain, and Pacific Fuel Co. Early use was by smelters in New Mexico, Arizona, Colorado, and northern Mexico. Several decades after the Colorado Fuel and Iron Corp.'s first production of pig iron and steel in 1881 at Pueblo, Colo., the Raton field began supplying much coke to the steel mills, and continued as an important market for New Mexico coal until 1954. With the development of the Kaiser Steel Corp.'s mines near Koehler and York Canyon, however, coking coal is again being mined from the Raton field and large tonnages are being shipped to Kaiser's coking ovens and steel mills at Fontana, Calif.

Mining methods.—Most of New Mexico's coal has been mined underground by drift or gently inclined slope mines. Strip mining has been introduced in New Mexico on a large scale only in recent years. The first stripping operations began on a small scale in 1945 in the Gallup field, McKinley County. With the opening in 1962 of the McKinley strip mine north of Gallup and in 1963 of the Navajo strip mine near Fruitland, the bulk of New Mexico production is now obtained by stripping methods.

COAL-BEARING AREAS

Most of the coal in New Mexico is concentrated in the San Juan Basin in the northwest corner of the State, and in the Raton field in the northeast corner. Smaller amounts are present in several small fields in the central and south-central part of the State. The areal extent and distribution of these fields are shown in figure 26, and they are discussed in more detail in separate paragraphs below.

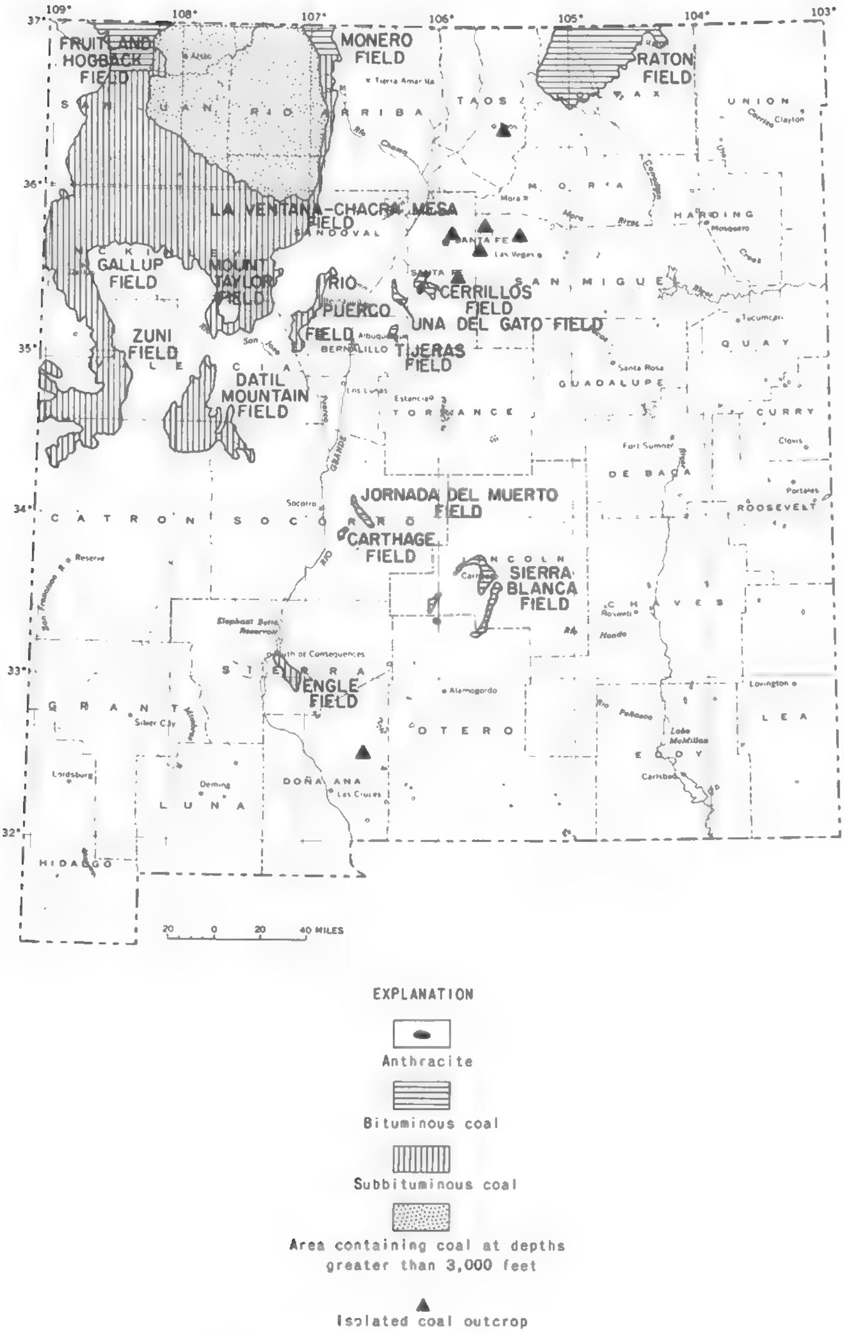

FIGURE 26.—Coal in New Mexico.

SAN JUAN BASIN

The San Juan Basin in McKinley, San Juan, Rio Arriba, and Sandoval Counties is the largest coal-bearing area in New Mexico (fig. 26). The coal crops out in a narrow belt around the edges of the Basin and dips under cover in all directions toward the center. The dips are gentle on the south and west sides, except near local anticlines, and are steeper on the north and east sides.

The thickest and best coals occur in the Mesaverde Group and in the Fruitland Formation of Late Cretaceous age. The beds in the Fruitland are thicker than those in the Mesaverde, but they contain interlaminated shale beds and have a higher percentage of ash. Local thin lenses of coal occur in the Cretaceous Dakota Sandstone and in the Paleocene Nacimiento Formation but do not have commercial potential.

Because of its large size, the San Juan Basin has been divided for purpose of discussion into several coal fields, or coal-producing districts, whose boundaries are determined primarily by access to railroads. The coal-bearing rocks are, however, essentially continuous throughout the Basin. These fields are described under separate headings below.

Gallup field.—The Gallup coal field (fig. 26) on the southwest edge of the San Juan Basin has been the site of more commercial mining than other areas in northwestern New Mexico. It is the site of several underground mines as well as the large McKinley strip pit of the Pittsburg and Midway Coal Co. Maps of the coalbeds and descriptions of the coal-bearing rocks have been published by Gardner (1909b), Sears (1925, 1934), and O'Sullivan and Beaumont (1957). The commercial coals occur in the Gallup Sandstone, in the Dilco and Gibson Coal Members of the Crevasse Canyon Formation, and in the Cleary Coal Member of the Menefee Formation, all of the Mesaverde Group.

The coals in Mesaverde Group are of subbituminous rank and of good grade. As many as three beds are found in the Gallup Sandstone with maximum thicknesses of about 3 feet; the Myers bed is the one most intensely mined. As many as nine coalbeds occur in the Dilco Coal Member with thicknesses of mined beds ranging from 4 to 7 feet. The Black Diamond coalbed is the most persistent bed of this member. Other main coalbeds are the Otero, Thatcher, Crown Point, and Defiance beds. Coalbeds in the Gibson and Cleary Members are variable in thickness and extent; probably at least five coalbeds occur within these units. Thickness of mined coals ranges from about 4 to 10 feet; the Aztec seam, the thickest of these beds, attains a maximum thickness of 10 feet including two shale partings near the top. Other important coalbeds are the Old Enterprise, Enterprise, and Clark.

All the coalbeds in the Gallup district are highly lenticular, and only a few can be traced more than several miles. Sears (1925, p. 24) noted that in one place the Gibson Coal Member contains eight coalbeds, each more than 14 inches thick, whereas a quarter of a mile away it contains not even one bed of this minimum thickness. Deposition of this type, which was common for most of the Cretaceous coals in New Mexico, probably was in small swamps scattered on the broad floodplains and coastal marshes of Late Cretaceous time. Locally, the coalbeds were trenched by streams after formation of the coal, and the

resulting channels filled with sand and silt. The shale partings found in many of the coal seams were caused by periodic flooding of the coal swamps by muddy waters.

The Gallup coal district lies on the southwestern side of the San Juan Basin at the northern end of the Gallup-Zuni embayment. This trough-like structural feature plunges gently northward into the San Juan Basin. The sedimentary beds dip steeply westward on the east edge of the city of Gallup at the Hogback, but westward the dips flatten to only a few degrees, then are reversed to dip gently eastward on the west side of the Gallup-Zuni trough. Minor anticlines, synclines, and faults complicate the structure locally.

The coalbeds of the McKinley strip mine of the Pittsburg and Midway Coal Co. are typical. Four fairly regular coalbeds are present, along with a fifth bed of erratic distribution (Coal Age, June 1962, p. 56-65) • the beds dip 3 to 5 degrees to the east or northeast, and are cut into fingerlike strippable areas by the southwestward drainage pattern. As is characteristic of much of the coal in the region, these coalbeds are extensively burned at the outcrop. The coalbeds have been mapped by Sears and Beaumont (O'Sullivan and Beaumont, 1957) as being entirely within the undivided Cleary and Gibson Coal Members of the Menefee and Crevasse Canyon Formations respectively. The stratigraphic section, with the intervals between the coals comprising varying thicknesses of sandstone and shale, and the coals named informally after the color used to show them on the outcrop map, is as follows :

	Thickness of interval in feet
Yellow coal	3 to 9
Sandstone and shale	14 to 21
Fuchsia coal	21/2 to 10
Sandstone and shale	21 to 40
Blue coal	4 to 15
Sandstone and shale	50 to 90
Brown coal (when present)	2 to 4
Sandstone and shale	15 to 20
Green coal	3 to 10

The "Blue" seam is now being mined and its sinuous outcrop occurs in secs. 5-8, 15-18, 21-23, and 27, T. 16 N., R. 20 W. and in secs. 12-14, T. 16 N. R. 21 W. The loading plant is in sec. 17, T. 16 N., R. 20 W.; coal is shipped 125 miles by rail to the Cholla power plant of the Arizona Public Service Co. near Joseph City, Ariz. About 380,000 tons were mined during 1963. The coal yields about 10,000 to 10,800 B.t.u. (British thermal units). Strippable reserves blocked out in advance of mining are estimated at 70 million tons.

Zuni field.—The coal-bearing Mesaverde Group crops out in the southern Gallup-Zuni basin to south of Zuni Salt Lake, about 90 miles south of Gallup. The upper part of the Mesaverde, however, has been removed by erosion in much of this southern area. The only coalbeds that remain are in the Gallup Sandstone and Dilco Coal Member of the Crevasse Canyon Formation. East of Zuni along the eastern edge of the Zuni Indian Reservation some of these coalbeds are as much as 5 feet thick locally but include several thick shale partings. Farther south, the lenses of coal appear to be fewer and the beds thinner.

Area between Gallup and Mount Taylor fields.—These Upper Cretaceous coals crop out along the southern flank of the San Juan Basin eastward from Gallup to the Mount Taylor field (Gardner, 1909b; Sears, 1934). Coals in the Gallup Sandstone in this area are merely

several lenses that only locally exceed 2 feet in thickness. The Black Diamond coalbed of the Dilco Coal Member occurs in the western part of the area but eastward this upper part of the Dilco is replaced laterally by the Dalton Sandstone Member, and the coalbeds present beneath the Dalton are equivalent to the lower part of the Dilco near Gallup. The Dilco coals are thin, in most places less than $3^1/_2$ feet thick; in the western part they are in two beds or zones of beds with other scattered lenses; eastward the upper zone intertongues into a barren sequence of sandstone and carbonaceous shale.

The Gibson Coal Member thickens eastward from Gallup and is separated from the Cleary Coal Member by the eastward-thickening Point Lookout Sandstone. The Cleary occurs as a continuous band to the north of Mesa de los Lobos and passes through Crownpoint. In several localities the coalbeds are about 5 feet thick. The Gibson Coal Member contains as many as six coalbeds and in many places extensive coal lenses range from 5 to 8 feet in thickness. At the Tohatchi mine (sec. 22, T. 17 N., R. 17 W., unsurveyed) the lowest coal of the Gibson is about 12 feet thick for an outcrop distance of more than a mile. Owing to the ruggedness of this mesa and canyon country, the coals have been mined only locally by the Navajos.

Mount Taylor field.—The Mount Taylor or San Mateo field (Hunt 1936; Gardner, 1910c) is in the southeast corner of the San Juan Basin and includes the rugged mesa country surrounding the ancient volcanic cone of Mount Taylor. Many lenticular beds of subbituminous coal are present in the Mesaverde Group. In most places they average about 15 inches in thickness, but locally they attain thicknesses of as much as 6 feet.

In the southern part of the Mount Taylor field the Mancos Shale is about 1,000 feet thick and is overlain by and intertongues with the predominantly terrestrial coal-bearing Mesaverde Group. Northward there is a rapid change in the lower part of the Mesaverde, the continental beds and nearshore sandstones become thinner and the marine shales thicken. Thus at the north edge of the Mount Taylor field the lower units of the Mesaverde grade laterally into the northward thickening Mancos Shale, which attains a maximum thickness of about 2,000 feet. Mesaverde coal-bearing beds above the Point Lookout Sandstone continue to the northeast into the La Ventana coal field.

The Dilco Coal Member contains a few thin lenses of coal about 2 feet thick in the western part of the field but to the east contains no coalbeds more than 14 inches thick. The Gibson Coal Member contains many coalbeds in the southern part of the field but grades northward into marine shale. About five coalbeds occur in most localities with the thickest coalbed found being 7 feet thick (Hunt, 1936) . Numerous thin coalbeds occur in the Cleary Member, a maximum of six beds being present. Most of the Cleary coals in this field are about 2 feet or less thick but some lenses reach 8 feet in thickness including shale partings.

Mining in the Mount Taylor coalfield has been confined to the accessible southern edge near U.S. Highway 66 and the A.T. & S.F. Railway where a few small coal mines have been operated for local use. Where not involved in local folding, the coalbeds dip gently northward, but not much of the area appears to be suitable for large-scale strip mining.

Rio Puerco field.—The Rio Puerco or La Caja del Rio Puerco field lies to the east of Mount Taylor and is not a part of the San Juan

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Basin, but its coal-bearing units are similar to those of the Mount Taylor field. The Rio Puerco coalfield is within a series of north-northeast aligned fault blocks bordering the Rio Grande structural depression on the west. Topographically, the southern part of the field, which is bisected by Rio Puerco, is a broad valley whose surface is broken by many low ridges and low mesas capped with resistant sandstone and separated by wide shale flats. The northeastern part of the field extends northward to the east of Mesa Prieta, a high basalt-capped mesa, and is a rolling, broken country along the divide between Rio Puerco and Rio Salado. In many places, the Cretaceous coal-bearing units are covered by thin to thick blankets of fine-grained alluvium and stream gravels.

Nowhere in the field are coals in the Dilco Member reported to exceed 14 inches in thickness (Hunt, 1936). In the southern part, bordering the A.T. & S.F. Railway and New Mexico Highway 6, coal lenses in the Gibson Member average 1 to 2 feet thick. Throughout the field, the Gibson unit contains a maximum of five coals more than a foot thick, and in the central and northern parts several lenses are 5 feet thick including shale laminae.

The Cleary Coal Member crops out mainly in the northern part of the field, and includes as many as six coalbeds averaging 2 or more feet in thickness, with lenses 3 to 4 feet thick being common. Several lenses as thick as 8 feet, including shale partings, have been mined at the north end of the field, 4 to 6 miles south of Rio Salado and New Mexico Highway 44. The coals occur in small fault blocks that dip at angles of 10 to 30 degrees, and thus are costly to mine.

La Ventana-Chacra Mesa field.—The La Ventana-Chacra Mesa coalfield is a northward extension of the Mount Taylor field and lies along the east edge of the San Juan Basin. Most of the field was mapped by Dane (1936) with the nomenclature later modified by Beaumont, Dane, and Sears (1956). Topography is typical mesa and cuesta landscape drained by intermittent streams in arroyos that feed into the Rio Puerco, the principal drainage channel of the eastern San Juan Basin.

Coal mining has been confined to the eastern part near State Highway 44 which formerly was paralleled by a branch railroad from the Rio Grande Valley. The coal is of subbituminous rank with high calorific value, but the beds are lenticular and very irregular in extent; some are as much as 5 to 9 feet thick, but most are 1 to 3 feet thick. The coals that have been mined and that are near transportation facilities are in the upper part of the Mesaverde Group in the Cleary Coal Member and Allison Member of the Menefee Formation. Farther westward along the southwest edge of Chacra Mesa, a few coalbeds occur locally in the lower part of the Cliff House Sandstone, the uppermost unit of the Mesaverde Group. In this western part of the La Ventana-Chacra Mesa field, commercial coals occur higher in the stratigraphic section in the lower and middle parts of the Fruitland Formation.

Near the village of La Ventana along the Rio Puerco Valley, the thickest and most persistent coalbed occurs in the upper part of the Allison Member. There are several other coal lenses in the upper part of the Allison Member; these appear to rise stratigraphically westward. Lower in the section in the Cleary Member there are four to seven beds more than 1 foot thick; several of these coalbeds are 5 to 9 feet thick, locally including some shale partings, and have been mined on a small scale. Along the east edge of the field the Cleary and Alli-

son coals dip 5° to 15° to the west or northwest; in the central part dips are mainly to the north and in most places less than 3°. In the western part, on and near Chacra Mesa, the strata dip gently to the northeast.

In the eastern part of the field, the Fruitland Formation contains little coal but in the western part on Chacra Mesa, Dane (1936) mapped as many as three beds more than 2 feet thick locally within the Fruitland. In the vicinity of Star Lake an impure coalbed 12 feet thick was observed by Beaumont. Of this total about 18 inches was thin interbeds of shale and siltstone and the upper 2 feet of coal was generally impure. Most of the Fruitland coals in this area contain many shale partings and much dispersed mineral matter. The structural-physiographic relationships are, however, favorable for strip mining in the western part of this field.

Monero field.—The Monero coalfield lies on the northeast edge of the San Juan Basin and has been a steady producer from small underground mines. Coal outcrops lie near U.S. Highway 84 and State Highway 17, as well as along the Denver and Rio Grande Western Railway. The coals occur in the Cleary Coal Member of the Menefee Formation of the Mesaverde Group (Dane, 1947; Gardner, 1909a). North of Monero this coal-bearing member grades into barren sandstone.

Coalbeds crop out in mesa and canyon country, with most of the mines within a few miles of Monero along the canyon of Amargo Arroyo and its side canyons. Three workable beds of excellent subbituminous to bituminous coal are known (Gardner, 1909a), but they tend to be thin (3 to 5 feet thick) and to contain partings and interbeds of shale and sandstone.

Fruitland-Hogback field.—The Fruitland-Hogback coalfield is a term applied herein to the coal-bearing area in the vicinity of the San Juan River in the northwestern part of the San Juan Basin. The coal occurs in the Menefee Formation of the Mesaverde Group and in the younger Fruitland Formation. These units are separated by about 1,500 feet of barren rock at the San Juan River.

Generally, the Cretaceous beds dip at low angles eastward into the San Juan Basin. Throughout much of the length of outcrop of the Mesaverde Group, it is involved in the sharp flexure of the Hogback monocline. In the vicinity of the San Juan River, the Fruitland beds are nearly flat-lying, but a few miles to the north of the river the Fruitland enters the folded belt of the Hogback monocline and continues with moderately steep dips into Colorado. U.S. Highway 550 passes through the area along the valley of the San Juan River, and the Denver and Rio Grande Western Railway reaches nearby Farmington.

Coalbeds occur in the Menefee and Fruitland Formations (Bauer and Reeside, 1921 ; Hayes and Zapp, 1955 ; Beaumont, 1955 ; Beaumont and O'Sullivan, 1955). The Menefee coals are of high-volatile bituminous rank and occur in two zones, one at the base and the other at the top of the formation. In the vicinity of the San Juan River, two main beds occur in the basal zone, averaging 6 feet thick where mined, but several other coalbeds are present; these are thinner and contain partings. Minable coalbeds in the lower Menefee disappear a short distance south of the San Juan River, but in this same area significant coal appears in the upper zone, which is essentially

barren at the river. Immediately south of Hogback Mountain a tongue in the upper part of Menefee contains about 40 feet of coal in beds more than 21/2 feet thick in a total sequence of rocks of about 180 feet. Two of these beds are 10 feet or more thick, but, involved as they are in the steep dips rif the Hogback fold, they have been mined only to very shallow depths at scattered localities for local use by the Navajos.

The thickest and best coals of the Fruitland are in the northern part of the Fruitland area ; southward the beds thin, becoming more lenticular and more shaly (Bauer and Reeside, 1921) . At least 16 coalbeds thicker than 30 inches occur in the formation, all in the lower and middle parts near the San Juan River but not more than 4 beds occur at any one locality. The coals are of subbituminous rank. The 2 beds that have been mined underground reach thicknesses respectively of 16 and at least 30 feet.

The Fruitland Formation coal mined at the Navajo mine of the Utah Construction and Mining Co. lies in the lower part of the formation south of the San Juan River. Several coalbeds ranging in thicknesses from 2 to 20 feet will be mined. The main coalbed being stripped in 1964 averages 12 feet in thickness, yields about 9,500 B.T.U., and overburden thickness ranges from 20 to 120 feet (Mining Congress Journal ; Jan. 1964, p. 19-21).

North of the San Juan River, the Public Service Coal Co. (a subsidiary of the Public Service Co. of New Mexico) has explored the stripping-coal potential of the Fruitland in the 6-mile interval between the Navajo and the Ute Mountain Indian Reservations. In this area dips are low, topography is favorable, and the coal occurs in a single bed locally as much as 20 feet thick.

West edge of San Juan Basin.—South of the Fruitland-Hogback area the Menefee Formation thickens and is exposed over a broad part of the western San Juan Basin. The lower coal-bearing zone trends southward beneath the Chuska Mountains. It contains only scattered thin coals of no economic importance; at a locality a few miles north of Gallup it is recognized as the Cleary Coal Member. About 30 miles south of the San Juan River the upper part of the Menefee swings southeastward toward the Chacra Mesa area. Intertonguing between the upper part of the Menefee and the overlying Cliff House Sandstone causes a considerable southward expansion of the Menefee, and coalbeds of considerable thickness and concentration are associated with the individual intertongues as described in a preceding paragraph. The intertonguing becomes less pronounced about 30 miles south of the San Juan River in the vicinity of Newcomb, and from there southeastward the upper zone contains only scattered coalbeds of significance.

South of the Utah Construction lease, the Fruitland coalbeds crop out in a belt that trends southward and thence southeastward toward the Star Lake area. The Fruitland is relatively flat-lying and contains as many as five coalbeds of minable thickness in a single locality. The attitude of the coalbeds with respect to the topography is favorable for strip mining throughout much of this area of outcrop, and extensive exploration has been undertaken by various groups both on and beyond the Navajo Reservation. El Paso Natural Gas Co. has drilled and evaluated the area from the Utah holdings southward to

where the Fruitland leaves the Reservation; and Public Service Coal Co. has explored an area of about 15 square miles immediately east of the Navajo boundary. In the latter area potentially strippable coal occurs in three beds, which range in thickness from $2^1/_2$ to 16 feet.

RATON FIELD

The Raton coalfield in northeastern New Mexico (fig. 26) lies on the western edge of the Great Plains in rugged, dissected plateau country just east of the Sangre de Cristo Mountains. Many west- to northwest-trending canyons reach into this plateau and provide easy access to the coalbeds, which are either almost horizontal or dip gently westward throughout the eastern and central parts of the field. The coals have been mined underground by driving horizontal drifts from the canyons; only in a few localities is the overburden thin enough to allow strip mining. U.S. Highway 85 (Interstate 25) and A.T. & S.F. Railway run along the east side of the coal field and provide access for shipping coal.

Minable coals occur in the Upper Cretaceous Vermejo Formation and the Upper Cretaceous and Paleocene Raton Formation (Lee, 1922, 1924; Wanek, 1963; Pillmore, 1964). Most of the coal is of high volatile bituminous rank and will coke. The Vermejo Formation thickens to the northwest and in general the contained coalbeds are more persistent in areal extent and in thickness than coalbeds of the Raton Formation (Read and others, 1950). Much of the coal mined from the field has been from the Vermejo Formation, in particular from the Raton coalbed, which lies in the lower part of the formation and has provided much coking coal. It is the coal mined in 1963 by the Kaiser Steel Corp. at Koehler. Where mined, the Raton bed is 5 to 15 feet thick.

The most mined and prospected coals in the Raton Formation are the Sugarite, Yankee, Tinpan, Potato Canyon, and York Canyon beds. The coals in the eastern and central parts of the field are in the lower and upper parts of the formation; minable lenses range from 3 to 13 feet in thickness with variable partings. The York Canyon bed was being developed in 1964 by Kaiser Steel Corp. to provide coking coal for their Fontana, Calif., steel plant when the Koehler mine is closed.

CERRILLOS FIELD

The Cerrillos coalfield is in west-central Santa Fe County in the broken foothill country north of the Ortiz Mountains and south of the broad valley of Rio Galisteo. The main line of the A.T. & S.F. Railway traverses the valley of Rio Galisteo along the north edge of the field, and State Highway 10 leads from Madrid in the center of the field north to Santa Fe and south to Tijeras. The coalfield is in a complex syncline; the beds are broken by many faults and they have been intruded by swarms of dikes and sills (Lee, 1913; Turnbull and others, 1951). The coals have been metamorphosed by thick igneous intrusive sheets to semianthracite and anthracite.

The coals are in the Mesaverde Group of Late Cretaceous age. Three major beds, ranging up to 6 feet in thickness, have yielded considerable tonnage of anthracite and bituminous coal ; from the base upward, the three coalbeds are the Miller Gulch, the Cook and White,

and the White Ash beds. Some of the bituminous lenses are coking coal. The coalbeds mined have been mostly 3 to 4 feet thick. The occurrence of anthracite is restricted to the White Ash bed where it is in close proximity to the intrusive rock and to a thinner unnamed bed immediately overlying the same intrusive body. Eastward from Madrid, the coal-bearing sediments are truncated by the Galisteo Formation of Eocene and Oligocene (?) age.

As much as 45,000 tons of anthracite were mined annually from the Cerrillos field during the period 1888 to 1957 and supplied to users throughout the central and western parts of the Nation. Freight costs, competition from natural gas and fuel oil, difficulties of mining, and problems with ash combined to close the anthracite mines near Madrid in 1957.

UNA DEL GATO FIELD

The Una del Gato coalfield lies in southeastern Sandoval County. The coal-bearing rocks are the approximate equivalents of the Mesaverde Group in the Cerrillos field. The coalbeds are 3 to 5 feet thick, of bituminous rank, and are cut by numerous faults (Campbell, 1907a). The area is reached only by ranch roads, and lies in a dissected lowland drained by Tongue Arroyo between the Sandia and Ortiz Mountains. Several small mines were operated near Hagen in years past, but the field's remoteness and the difficulties of mining caused by the complex structure closed the mining operations. Hagen is now an almost vanished ghost town.

TIJERAS FIELD

The Tijeras coalfield is in northeastern Bernalillo County amid the rolling foothills of the Sandia Mountains. U.S. Highway 66, Interstate 40, lies along the southeast, edge of the field and New Mexico Highway 10 parallels the northwest margin. The coalbeds are in the Mesaverde Group and crop out in a small down-dropped fault block, the Tijeras graben.

The coal-bearing strata are folded into two synclines and an intervening anticline, and dip relatively steeply (average range of 10° to 40°). Several thin beds of bituminous coal crop out, but only a few tons have been mined for blacksmithing and minor local use (Lee, 1912).

DATIL MOUNTAIN FIELD

The most remote and the least known coal-bearing area in New Mexico is the Datil Mountain field. It covers more than 1,000 square miles in Socorro, Catron, and Valencia Counties. The region is composed of rough foothills, mountains, canyons, and mesas, is transected by Rio Salado, and is reached with difficulty on ranch roads that connect with U.S. Highways 66 and 60 to the north and south, respectively. The coal occurs in the Mesaverde Group and is of subbituminous rank.

The known coalbeds are thin, in most places less than 3 feet thick. They are broken by many faults, and locally are complexly folded as well as intruded by igneous rock bodies (Tonking, 1957; Givens, 1957; Winchester, 1921). Coal outcrops are relatively numerous even though observations have been made mainly near the few ranch

roads in the area; more detailed studies may reveal lenses of coal of minable thickness in some localities.

CARTHAGE FIELD

The Carthage coalfield lies in east-central Socorro County. The field lies on the northwest edge of Jornada del Muerto, an extensive semiarid plain of south-central New Mexico, and is crossed by U.S. Highway 380, 12 miles east of the A.T. & S.F. Railway station of San Antonio. Two coalbeds that range from 4 to 7 feet in thickness occur in the lower part of the Mesaverde Group. Only the lower coal, the Carthage bed, has been mined. It is excellent quality coking coal of bituminous rank (Gardner, 1910b) . The upper coalbed is more erratic in thickness, contains much ash, and many shale partings.

This small field, occupying about 10 square miles, is cut into many small blocks by faults, thus increasing the difficulty and cost of mining. U.S. Army troops stationed at nearby Fort Craig opened the mining in this field in 1861, the earliest mining of coal in New Mexico on a scale of more than a few wagonloads a year. The Carthage coalfield once supplied coking coal to smelters in southwestern New Mexico and northern Mexico, but in 1964 only a single small mine operated, providing coal for local heating.

JORNADA DEL MUERTO FIELD

Five to twenty miles east and northeast of the Carthage field, Mesaverde coals underlie the northeast edge of Jornada del Muerto in an area known as the Jornada del Muerto field. Windblown sand conceals much of the bedrock. The area is remote and is reached only by ranch roads, and there has been no mining. The coal is of bituminous rank, similar to that of the Carthage field, but the few reports available (Read and others, 1950) shows maximum thicknesses of only 3 feet for the coal outcrops.

SIERRA BLANCA FIELD

Coalbeds of the Sierra Blanca or Capitan coalfield also occur in the Mesaverde Group and have been mined near Capitan, Fort Stanton, White Oaks, and Carrizozo in Lincoln County (Campbell, 1907b; Wegemann, 1914 ; Bodine, 1956 ; Griswold, 1959). Resources of coal appear to be large but the coal-bearing beds are broken by many faults and intruded by many igneous dikes and sills associated with the igneous complex of Sierra Blanca. U.S. Highway 380 crosses the field in an east-west direction, and U.S. Highway 54 and the Southern Pacific Railway lie a few miles to the west. Outcrops of the Mesaverde Group and of the coalbeds form a broken semicircle on the west, north, and east sides of the igneous complex of Sierra Blanca.

Most of the coal is of bituminous rank, and several lenses as much as 7 feet thick have been mined. An unusual number of sandstone "rolls," lenses of sandstone that replace parts of the coalbeds, are present and increase the difficulty and uncertainty of mining. The field has been essentially inactive since 1910.

ENGLE FIELD

In central Sierra County, several thin coalbeds occur in the Mesaverde Group of the Engle field, east and northeast of the Caballo Mountains. Several prospect pits were opened in thin lenses (8 to 15 inches thick), and drill holes have penetrated several coalbeds with maximum thickness apparently being 2 feet (Lee, 1906; Kelley and Silver, 1952).

OTHER OCCURRENCES

In the southwestern San Andres Mountains near Love Ranch in northeastern Dona Ana County, a coal lense 2 feet thick in rocks of Eagle Ford (Late Cretaceous) age was mined for use at Fort Selden in the late 1860's (Kottlowski and others, 1956). Coalbeds of that age have been mined on a small scale in the Juarez Mountains of northern Mexico a few miles south of the New Mexico-Mexico border.

Thin lenticular coals of Pennsylvanian age crop out in the Sangre de Cristo Mountains west of Las Vegas, at several areas north of Pecos along the Pecos River canyon, near Lamy, near Sante Fe, and southeast of Taos (Gardner, 1910a; Kottlowski in Spiegel and Baldwin, 1963 ; Schilling, 1960). Several of the coal lenses in these areas are as much as 4 feet thick and have been mined on a small scale for local use. Farther south, in south-central New Mexico, only coal laminae occur amid the Pennsylvanian rocks (Kottlowski, 1960) .

COAL RESOURCES

The coal resources of New Mexico are estimated (table 13) at about 62 billion tons, of which 50.8 billion tons are subbituminous, 10.9 billion tons are bituminous, and 6 million tons are anthracite (Read and others, 1950 ; Averitt, 1961). The Raton coalfield contains at least 4.7 billion tons of bituminous coal, and San Juan County contains as much as 4.1 billion tons of bituminous coal, but a large part of the total is deeply buried. The largest resources of subbituminous coal are in San Juan County (32.5 billion tons) and McKinley County (13.2 billion tons). Much of the total in these areas is more than 1,000 feet below the surface. All anthracite resources are in the Cerrillos field of Santa Fe County. In contrast to these huge resources, the total cumulative coal production reported in New Mexico through 1963 was a mere 129 million tons.

In addition to the usual classifications of the U.S. Geological Survey (Averitt, 1961), a category of resources termed "inferred by zone" was established (Read and others, 1950) to include resources that could not be determined by conventional methods. Many of the Mesaverde and Fruitland coals commonly occur in zones as a series of lenticular deposits interbedded with other sedimentary rocks. Individual coalbeds are limited in extent, but the coal-bearing zones are very persistent and cover large areas. The classification method did not permit the usual breakdown of resources according to thickness of beds, but the huge total in this category obviously includes much thick coal.

TABLE 13.—*Estimated original coal resources of New Mexico*[1]

[In millions of short tons]

Overburden (feet)	Thickness of bed (inches)	Resources: Measured	Indicated	Inferred	Inferred by zone	Total
BITUMINOUS COAL						
0 to 1,000	Thicker than 14				2,378	2,378
	14 to 28	73	359	335		767
	28 to 42	152	334	27		513
	Thicker than 42	429	612	360		1,401
		654	1,305	722	2,378	5,059
1,000 to 2,000	Thicker than 14				1,763	1,763
	14 to 28	1	7	694		702
	28 to 42		39	356		395
	Thicker than 42		70	715		785
		1	116	1,765	1,763	3,645
2,000 to 3,000	Thicker than 14				1,839	1,839
	14 to 28		2	25		27
	28 to 42		1			1
	Thicker than 42			377		377
			3	402	1,839	2,244
Total		655	1,424	2,889	5,980	10,948
SUBBITUMINOUS COAL						
	Thickness (feet)					
0 to 1,000	Thicker than 2½				16,363	16,363
	2½ to 5	447	1,021	1,227		2,695
	5 to 10	228	348	998		1,574
	Thicker than 10	151	162			313
		826	1,531	2,225	16,363	20,945
1,000 to 2,000	Thicker than 2½				13,155	13,155
	2½ to 5		61	165		226
	5 to 10		39	744		783
	Thicker than 10		121	538		659
			221	1,447	13,155	14,823
2,000 to 3,000	Thicker than 2½				13,288	13,288
	2½ to 5		4	502		506
	5 to 10		12	448		460
	Thicker than 10					
			16	1,729	13,288	15,033
Total		826	1,768	5,401	42,806	50,801
ANTHRACITE						
	Thickness (inches)					
0 to 1,000	14 to 28	1	2			3
	28 to 42	1	1			2
	Thicker than 42	1				1
		3	3			6
Total		3	3			6
Total, all ranks		1,484	3,195	8,290	48,786	61,755

[1] After Read and others, 1950.

CONCLUSIONS

New Mexico's substantial coal resources are located favorably in relation to the growing population and industrial centers of southern Arizona and southern California. As the energy needs of these and adjoining areas increase, it is likely that they will be interconnected by high-voltage, direct-current, long-distance transmission lines as proposed in September 1964 by an association of 10 of the largest electric utility companies operating in the southwest. Representatives of this association, known as WEST associates, have predicted that the generating capacity of the member utilities will double by 1986. Much of this increase can, and probably will be supplied by very large steam generating plants located near sources of low-cost, strip-mined coal which New Mexico can supply in abundance.

ASPHALT AND OTHER BITUMENS

(By R. W. Foster, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Hydrocarbon-bearing rocks other than coal, oil shale, or those that contain petroleum are widespread in the United States and other parts of the world. Most bituminous sandstones and limestones (rock asphalts) represent former concentrations of crude oil that have been exposed to surface weathering and subsequent loss of the lighter volatiles ; others are primary deposits of asphaltic material. Until recently, the most important use for this material has been as road asphalt. Rock asphalts are now considered possible sources of crude oil. A heavy oil may be obtained from these bitumen-impregnated sandstones and limestones by mining and retorting or by introducing hot water or steam into the formation to lower the viscosity and drive the oil to wells from which it may be pumped to the surface. The Athabaska tar sands of western Canada and the asphaltic sandstones of northeastern Utah represent large reserves of crude oil, and considerable research has been done in recent years to determine the amount of contained oil and the most economical methods of extraction.

Numerous bituminous sandstone or limestone deposits have been found in New Mexico (fig. 27). Only two occurrences, the deposits near Santa Rosa, Guadalupe County, and Gallup, McKinley County, appear to be extensive enough to warrant further investigation.

SANTA ROSA SANDSTONE

The asphalt deposits in the Santa Rosa Sandstone of Triassic age have been described by Winchester (1933), Bates and others (1942), and Gorman and Robeck (1946). The sandstone contains asphalt over a known area of about 14 square miles north of the town of Santa Rosa. Bitumen content ranges from a trace up to 9.1 percent by weight. The higher percentages have been obtained from core samples ; weathered outcrop samples having a maximum content of about 5 percent asphalt have been reported. Saturated zones vary in thickness from 10 to 60 feet, and reserves of sandstone containing 4 percent or more of asphalt have been estimated at more than 100 million tons.

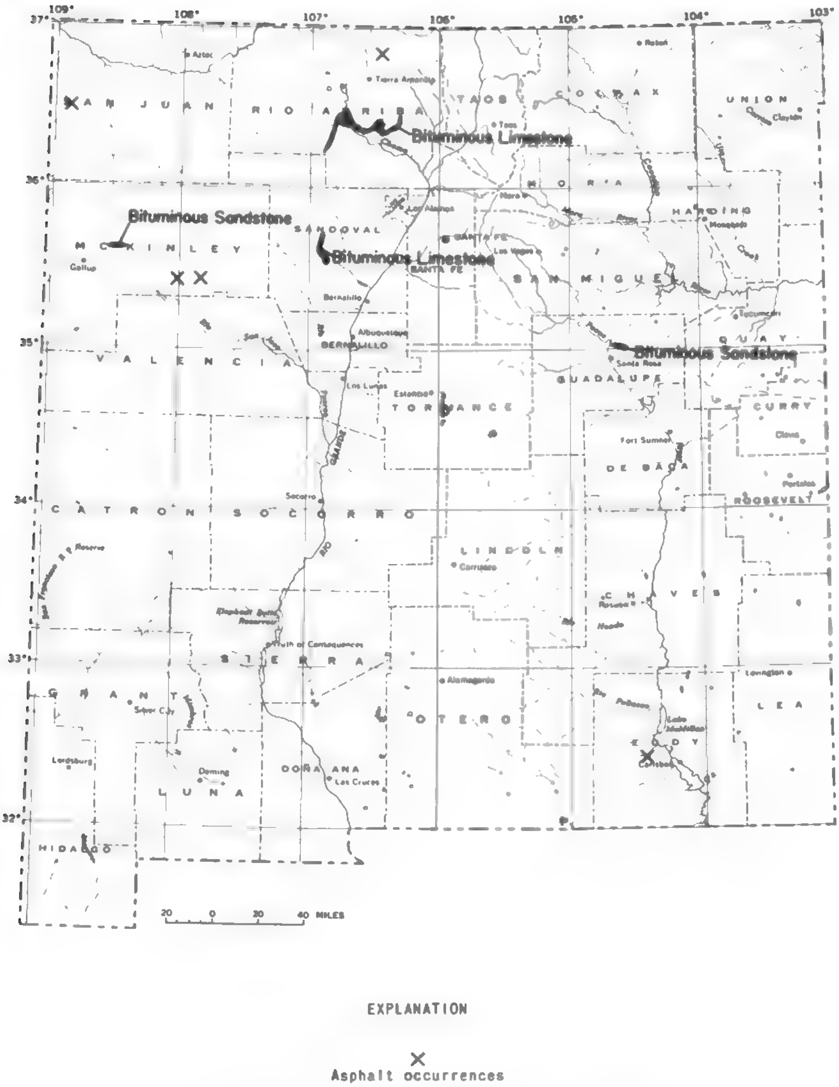


FIGURE 27.—Asphalt rocks in New Mexico.

Surface samples from lean and rich-appearing rocks were subjected to destructive distillation in the New Mexico Bureau of Mines and Mineral Resources retort and yielded from about 4 to 12 gallons of oil per ton of rock. Gas loss during retorting amounted to about 1 percent of the total weight of the sample. The oil obtained is dark yellow-brown, fluid at room temperatures, and has a specific gravity of 0.925 (21.3° API) at 60° F. The total bitumen content of the richer samples varied from 6 to 7 percent; therefore, somewhat higher yields might be expected from fresh samples.

More than 150,000 tons of Santa Rosa Sandstone have been quarried for use as road asphalt in the Santa Rosa area and adjacent parts of New Mexico, Colorado, Oklahoma, and Texas. The sandstone was crushed at a small mill near the quarry, mixed with a small amount of additional asphalt and gasoline or naptha, and laid cold. The operation is presently inactive.

GALLUP SANDSTONE

An oil-saturated sandstone occurs in the Gallup Sandstone about 15 miles northeast of Gallup, N. Mex., in T. 16 N., R. 16 W. According to data received by Winchester :

> The sandstone is saturated with a paraffin base oil over a relatively large area * * *. The saturated sandstone has a thickness of not over 40 feet * * * and an oil content of as much as 24 percent.

There is no additional published information concerning this deposit, and the total area underlain by the saturated sandstone is not known.

MISCELLANEOUS DEPOSITS

The Todilto Formation of Jurassic age contains small amounts of soluble bitumen over a considerable part of central Rio Arriba and Sandoval Counties. Surface samples of the limestone from the formation were collected from the outcrop belts south of Tierra Amarilla. The highest oil yields obtained amounted to less than 2 gallons per ton of limestone. Bituminous material has also been reported from this limestone at outcrops near Grants where the bitumen is associated with uranium deposits.

Little is known of other reported occurrences of bituminous material outcropping in New Mexico, and attempts to relocate some of these seeps or deposits have not been successful. Oil seeps or asphaltic sandstones have been reported in the Gallup Sandstone on Beautiful Mountain anticline in sec. 12, T. 26 N., R. 20 W. in San Juan County and in the Entrada Sandstone of Jurassic age, 5 miles east of Chama, Rio Arriba County.

Asphaltite has been reported associated with uranium in McKinley and Eddy Counties. The bitumen is low in hydrogen, and it has been suggested that it was derived from coalified wood instead of petroleum. Similar occurrences have been noted in the Abo Sandstone of Permian age in Socorro, Torrance, and Valencia Counties.

OIL SHALE

(By R. W. Foster, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Oil shale is a fine-grained sedimentary rock that will yield a petroleum-like substance by destructive distillation. Other bituminous rocks that contain soluble hydrocarbons and that will yield oil by heating are discussed in a separate section of this report. (See asphalt chapter.) Excluded from this discussion are shales that contain natural crude oil that may be extracted by conventional drilling and production methods.

The organic matter in oil shale consists of kerogen derived mostly from aquatic plant algae of high molecular weight hydrocarbons containing nitrogen, oxygen, and sulphur. Upon heating, the organic matter in the shale converts to a soluble bitumen and at approximately 350° C., vapors condense to form a highly viscous liquid that may be refined to produce gasoline, kerosene, fuel oil, asphalt, waxes, and other petroleum products.

Oil shales vary from black to brown and yellow, plus various shades of gray. They may be massive with a conchoidal fracture or they may consist of fissile, "paper" shales. Some have a waxy luster; others are dull and stony in appearance. Some "oil shales" are not true shales but consist largely of calcium and magnesium carbonate. Although some oil shales are intimately associated with coalbeds, such as those in Spain, Scotland, France, and Australia, others, such as those in the United States, Estonia, and Sweden, are not. Deposits of oil shale occur in almost every part of the geologic column. Deposits in Sweden are Cambrian or Silurian in age; some beds in Canada are Devonian, Permian oil shales occur in Brazil, Triassic in Austria, ,Turassic in Germany, Cretaceous in Israel, and Tertiary in the United States.

Shale oil has been or is presently being produced in Sweden, Great Britain, Spain, Australia, France, South Africa, Estonia, China (Manchuria) , New Zealand, Canada, Brazil, Austria, and Switzerland. Other deposits have been found in the United States, U.S.S.R., Thailand, Israel, Congo, Bulgaria, Burma, Czechoslovakia, Germany, Italy (Sicily) , and Yugoslavia. The largest known deposits are in Colorado, Utah, and Wyoming and near Sao Paulo, Brazil.

At the present time, the production of oil from shale is a marginal economic operation. In general, to compete with naturally occurring petroleum, the yield should average about 25-30 gallons of oil per ton of shale, and the retorting process must obtain a high yield percentage and generate sufficient gases to operate the retort. It is preferable also that the shale can be stripped to reduce mining costs, although large-scale, room-and-pillar methods of mining may prove practical. In situ extraction methods have been attempted on an experimental basis in deposits in the Eocene Green River Formation of Colorado and are presently used on a small scale in Sweden. Underground atomic explosions have also been suggested as a possible means of extracting the oil from the shale.

No oil-shale deposits are known in New Mexico, but until the last few years they have not been really looked for in the State. The only published reference to oil shale in New Mexico is by Winchester (1933), who stated :

> A small sample of black shale from the upper part of the Magdalena formation "near Scholle," * * * was subjected to distillation and found to yield oil at the rate of 41 gallons per ton. This is exceptionally rich for shales of Pennsylvanian age. Several of the black shale beds of the section were tested by the writer and found capable of yielding oil on distillation.

In 1961, the New Mexico Bureau of Mines and Mineral Resources began a limited exploration program in the State, and additional support was given by the State Planning Office in 1963. Since the project was initiated, more than 3,500 qualitative tests have been conducted, primarily on rocks of Pennsylvanian age. Laboratory equipment similar to that used by the U.S. Bureau of Mines at its Laramie Research Center is now in use, and quantitative data are being collected.

Shales that are potential sources of shale oil are abundant in New Mexico, mostly in rocks of Devonian, Pennsylvanian, Cretaceous and Tertiary ages.

Rocks of Devonian age are generally thin and crop out on steep slopes beneath thick, resistant Mississippian limestones. To date, no Devonian black shales have been tested, although some sampling and retorting is planned. Because of the narrow outcrop belt and thick limestone caprock, underground mining would be necessary ; unless yields are exceptionally high, it is doubtful that these shales will be of commercial importance.

The Pennsylvanian sequence contains thick shales and is widely exposed from north to south through the central part of the State. Exceptionally thick, dark shales crop out in Socorro County in the southeastern part of the San Mateo Mountains and in western Mora County in the Sangre de Cristo Mountains. Qualitative tests made on well and surface samples through the Pennsylvanian interval gave encouraging positive results, particularly in the lower part of the section in Socorro and Torrance Counties. Like the Devonian beds, outcrops of Pennsylvanian shales, though thick and numerous, are not amenable to strip mining in most areas.

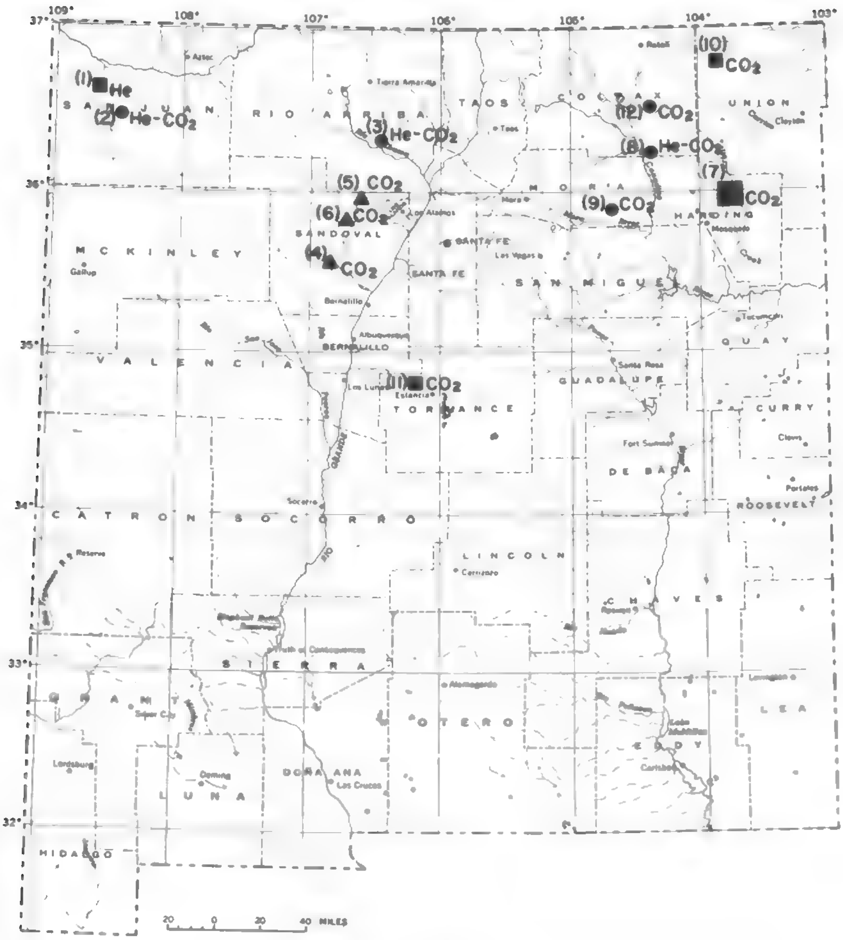
The most extensive outcrops of dark shales in New Mexico occur in beds of Cretaceous age. Shale intervals are thick and underlie large areas in the northwestern and northeastern parts of the State. Other important exposures are known south of Santa Fe, around Capitan in Lincoln County, and east of the Caballo Mountains in Sierra County.

Rocks of Tertiary age are exposed over most of New Mexico, but only in the central parts of the San Juan and Raton Basins are they of interest for oil shale. In these areas a few indications of oil have been noted during qualitative testing of well samples.

HELIUM

(By A. P. Pierce, U.S. Geological Survey, Denver, Colo.)

Helium is a light, inert gas with numerous critical uses in modern technology. In recent years large quantities have been required for its application as a pressurizing medium for liquid fuel missiles and rockets, such as the Atlas, Titan I, and the new Saturn-class rockets. Currently, about 45 percent of U.S. helium production goes toward this purpose (Lipper, 1964). Other applications include use of helium as an inert medium in shielded-arc welding, in growing tran-



EXPLANATION

Gas field

Gas occurrence in exploratory well

Mineral spring

He
Helium occurrence

CO_2
Carbon dioxide occurrence

FIGURE 28.—Helium and carbon dioxide in New Mexico (numbers refer to localities in text and table 14).

TABLE 14.—*Natural gas containing helium and carbon dioxide*

Sample No.	County	Sec.	T.	R.	Field	Well	Production: Stratigraphic Position	Production: Geologic Age	Production: Depth (feet)
1	San Juan	3	27N	17W	Table Mesa	Continental Oil Co.-- Table Mesa No. 3-18	Paradox Member, Hermosa Formation	Pennsylvanian	7,096
2	San Juan	32	26N	15W	Navajo Tract 23	Pine Oil Co.-- No. 1	Leadville Limestone	Mississippian	10,079
3	Rio Arriba	14	24N	5E	Abiquiu	Lowry et al Morten No. 1	Contact of Pennsylvanian and Precambrian Granite		1,732
4	Sandoval				---	San Ysidro Springs	Wingate and Chinle Formations	Triassic	Spring
5	Sandoval				---	Sulphur Springs	Undifferentiated Volcanic Rocks	Tertiary	Spring
6	Sandoval				---	Jemez Springs	Contact of Pennsylvanian and Precambrian Granite		Spring
7	Harding	34	21N	30E	Bueyeros	Power-Marshall Co.-- No. 1	Sangre de Cristo Formation	Permian and Pennsylvanian	1,900
8	Colfax	15	23N	24E	Jaritas dome	Florshiem State No. 1	Santa Rosa Sandstone	Triassic	1,509
9	Mora	11	19N	21E	Wagon Mound	Arkansas Fuel Co.-- C. F. Cruse No. 1	Santa Rosa Sandstone	Triassic	1,420
10	Union	4	29N	29E	Des Moines	Sierra Grande Oil Corp. Rogers No. 1	Santa Rosa Sandstone	Triassic	1,188
11	Torrance	12	6N	7E	Estancia Valley	Estancia Valley CO_2 Dev. Corp.—Witt No. 1	Magdalena Group	Pennsylvanian	1,293
12	Colfax	2	26N	24E	Maxwell	York Denton State No. 1	Santa Rosa(?) Sandstone	Triassic	1,515

TABLE 14.—*Natural gas containing helium and carbon dioxide*—Continued

Wellhead pressure (p.s.i.)	Open flow (Mcf/day)	Components (percent) Hydrocarbons	Nitrogen	Oxygen	Argon	Helium	Hydrogen	Hydrogen Sulphide	Carbon Dioxide	Source of Data
3,037	21,500	29.2	62.1	tr.	0.5	4.7	0.0	0.0	0.3	Miller and Norell (1964)
---	---	1.8	2.2	tr.	tr.	0.5	tr.	0.0	95.3	Miller and Norell (1964)
690	---	0.2	1.7	0.1	tr.	0.41	1.0	---	96.5	Boone (1958)
---	---	0.0	2.0	0.5	---	0.0	---	0.0	97.5	Renick (1931)
---	---	0.0	0.9	1.1	---	0.0	---	20.1	77.9	Renick (1931)
---	---	0.0	13.9	3.3	---	0.0	---	0.0	82.8	Renick (1931)
520	1,000	0.0	0.2	tr.	tr.	0.01	tr.	---	99.7	Boone (1956)
---	250	0.0	28.7	4.1	---	0.46	---	---	67.2	Anderson and Hinson (1951)
---	12,000 estimated	---	6.7	1.1	---	0.15	---	---	92.2	Anderson and Hinson (1951)
---	show	---	1.1	0.4	---	0.0	---	---	98.4	Anderson and Hinson (1951)
400	250	---	2.1	---	---	0.08	---	---	97.9	Anderson and Hinson (1951)
128	153	---	---	---	---	---	---	---	99.8	Talmadge and Andreas (1942)

sistor crystals, in wind tunnels, shock-tubes, and in plasma arc studies. Helium is used as a lifting gas in weather ballons, as a cryogenic agent in low temperature research, and as a heat-transfer medium in gas-cooled nuclear reactors for power generation. Because of its many uses, future demand for helium is expected to increase. Known resources are limited, and this has led to a conservation program designed to recover helium from natural gas containing 0.3 percent or more helium (Lipper, 1963, 1964) .

The helium found in natural gas fields is generally believed to have formed through radioactive decay of uranium and thorium in adjacent and underlying rocks. The highest concentrations of helium are found in natural gas deposits in sedimentary rocks of relatively old geologic age that overlie buried uplifts or occur in shelf areas on the flanks of sedimentary basins (Pierce, 1960). The first discovery of a helium resource in New Mexico was in natural gas found in the Ouray Limestone of Devonian age in a well drilled into the Rattlesnake dome, San Juan County in 1942 (Hinson 1947). A helium extraction plant was built by the U.S. Bureau of Mines at Shiprock to process the gas. Since 1942, further occurrences of helium-rich gas have been noted in gas from "shows" and drill-stem tests in sedimentary rocks of Mississippian and Pennsylvanian age in exploratory wells throughout the Four Corners platform, a structural feature (Kelley, 1955) that occupies the area northwest of the San Juan Basin (fig. 28). The concentration of helium among the known gas occurrences tends to increase with depth and with proximity to Precambrian rocks that compose the basement complex of the Four Corners platform and the Defiance uplift of Arizona bordering the western flank of the San Juan Basin (Picard, 1962). Some helium occurrences in natural gas are given in table 14.

In 1961, helium-bearing gas (sample No. 1, table 14) was discovered in the Paradox Member of the Hermosa Formation of Pennsylvanian age in the Table Mesa field. The field has an estimated recoverable helium reserve of 850,000 MCF (thousand-cubic feet), and currently supplies gas containing about 5.4 percent helium to the Bureau of Mines helium extraction plant at Shiprock (Miller and Norell, 1964). The helium production of this plant in 1963 was 78,252 MCF at a value of $2,739,000 (U.S. Bureau of Mines, 1964) .

The origin of the unusually high concentrations of helium in the natural gas of the Four Corners platform is only partially understood. Studies of the isotopic composition of the helium and of the argon that is associated with it indicate that both kinds of gas are of radiogenic origin and were probably derived together from rocks that contained normal proportions of uranium, thorium, potassium, and other elements (Morrison and Beard, 1949: Zartman, Wasserburg, and Reynolds, 1961). The factors responsible for the unusual enrichment of helium in the gas reservoir rocks, however, are unknown. From its regional distribution the helium is believed to have been derived through degassing of underlying Precambrian rocks, possibly as the

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result of Tertiary igneous activity in this area (Dobbin, 1935; Picard, 1962).

Gas "shows" containing more than 0.3 percent helium have been reported in wells from two localities in New Mexico that are outside the Four Corners platform (samples 3 and 8, table 14). Both occurrences are in association with carbon dioxide gas, and occur in regions that have been affected by Tertiary and Quaternary igneous activity.

CARBON DIOXIDE

(By A. P. Pierce, U.S. Geological Survey, Denver, Colo.)

Carbon dioxide is an odorless, chemically inert gas having a density about 1$^1/_2$ times that of air. The gas is exceptionally soluable in water, more so in cold water. The critical temperature of carbon dioxide is 31.1° C., and below this temperature is can be liquified by pressure alone. When cold liquid carbon dioxide is allowed to expand from under pressure it sublimes to form a snow having a temperature of —78.3°C. which is compressed into blocks to make "dry ice."

Carbon dioxide gas is used to make carbonated beverages and is employed as an inert shield in the manufacture of chemicals and in fire-fighting. Large quantities of liquid and solid carbon dioxide are used for in-transit refrigeration of fruit and vegetable trucks and railroad cars. A part of the carbon dioxide in New Mexico is sold to Sandia Base and Holloman Air Force Base for cryogenic purposes in laboratory experiments and missile firing.

New Mexico ranks first among the States in annual production of natural carbon dioxide, but the amount produced is only a few percent of the U.S. annual production of natural and manufactured carbon dioxide. Most carbon dioxide is recovered from industrial waste gas at coke, petrochemical, cement, metallurgical, and other plants. New Mexico produced 826,810 MCF of carbon dioxide,[1] valued at $74,000 (estimated well-head value) during 1962 (U.S. Bureau of Mines, 1964). U.S. shipments of carbon dioxide during the same year were 945,000 short tons having an estimated value of $49.7 million (Business and Defense Services Administration, 1964) .

Carbon dioxide has been encountered during exploratory drilling for oil and gas at widely scattered localities in northern New Mexico (fig. 28 ; table 14). A few of the occurrences have contained gas of high purity in adequate quantity to warrant commercial development. A plant located near the Estancia Valley field (fig. 28) produced dry ice from 1934 to 1942, when the field was abandoned due to subsurface water encroachment. A plant near the Des Moines field produced liquid carbon dioxide during 1955 to 1957. Since 1931 the major part of the carbon dioxide production has been from the Bueyeros field in Harding County.

The Bueyeros and Des Moines fields (Nos. 7 and 10, fig. 28), which contain the principal known carbon dioxide resources, are located on the Sierra Grande arch of northeastern New Mexico. The wells in these fields produce carbon dioxide from sandstones of Triassic age and from arkosic sedimentary rocks of Permian and Pennsylvanian age that flank the Precambrian rocks of the arch. The Bueyeros and Des Moines fields and also the wells with carbon dioxide "shows" in the Wagon Mound, Maxwell, and Jaritas dome areas (Nos. 8, 9, 12, table 14, fig. 28) are each located within a few miles of outcrops of volcanic and igneous rocks of Tertiary and Quaternary age that occur in numerous vents, flows, dikes, and sills throughout the northern part of the Sierra Grande arch. In addition to the surfaces occurrences of igneous rock, a well in Union County is reported to have penetrated sills that intrude Triassic and Permian sedimentary rocks at depth

[1] Equivalent to about 41,000 tons at a conversion factor (U.S. Interagency Commission, 1955) of 20,000 cubic feet of carbion dioxide to 1 ton of dry ice.

(Neiler, 1956). The carbon dioxide on the Sierra Grande uplift is commonly believed to be related to late Tertiary and Quaternary igneous and metamorphic activity. Germann (1938) proposed that heat from igneous intrusions caused carbonate minerals in the sedimentary rocks to decompose and react with silica to produce the carbon dioxide. The same view is held by Lang (1959) who showed that the isotopic composition of the carbon in the Bueyeros gas is typical of that found in carbonate minerals of limestones. The volcanic sequence near the Des Moines field in Union County includes nepheline basalts believed by Stobbe (1949) to result from reaction of magmas with limestone at depth ; however, Muehlberger (1959) attributes the compositions of the volcanic rocks to magmatic differentiation.

The widespread occurrence of geologically young igneous rocks in New Mexico and the presence of carbon dioxide "shows" in exploratory test wells in widely scattered localities on the Sierra Grande arch and in other parts of the State indicate a favorable potential for discovery of further resources. Carbon dioxide with a significant percentage of helium (sample 3, table 14) has been reported from a gas "show" in sedimentary rocks of Pennsylvanian age in a well near Abiquiu in Rio Arriba County. The well is located about 10 miles north of vents, dikes, and flows of volcanic rocks of Quaternary age associated with the jemez volcanic uplift (fig. 28). Natural gas samples from a series of hot springs in and near the southwestern border of the Jemez volcanic uplift contain high percentages of carbon dioxide (samples 4, 5, 6, table 14) . On the Four Corners platform of northwestern San Juan County carbon dioxide has been reported in a number of drill stem tests in carbonate rocks of Mississippian age (Picard, 1962). The area contains intrusions of igneous rocks of Tertiary age (fig. 28). Sample 2, table 14 is an analysis of gas from one of these occurrences.

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METALLIC MINERAL RESOURCES

GOLD

(By M. H. Bergendahl, U.S. Geological Survey, Denver, Colo.)

The durability, appearance, relative scarcity, and malleability of gold have contributed to its historic status as a precious metal, and as a consequence, the chief use of gold is in monetary systems, as coinage or as backing for currency. Considerable gold is used in manufacturing jewelry and in plating, binding, lettering, gilding, and interior decoration. Some gold is used in dentistry, the chemical industry, and glassmaking. Because of its resistance to corrosion and its infrared reflective properties, gold has certain uses in scientific instrumentation.

Gold occurs in a variety of natural forms : as the native element associated with quartz or metallic sulfides, alloyed with silver as electrum, or as gold telluride minerals, the most common of which are calaverite, sylvanite, krennerite, and petzite. More rarely gold occurs in compounds with mercury, bismuth, and chlorine.

HISTORY AND DEVELOPMENT

Mining began in New Mexico long before mineral discoveries were made in any of the other Western States. The copper deposits at Santa Rita were worked late in the 18th century, and placer gold mining was conducted as early as 1828 in the Ortiz Mountains south of Santa Fe. Gold lodes were mined in 1833 in the Ortiz Mountains.

New Mexico was incorporated as a Territory of the United States at the close of the Mexican War in 1846, but, because of its isolation, the general lack of knowledge of the region, and the hostility of the Apache Indians, prospectors and miners did not explore the new acquisition to any extent until after 1860. All mining in the Territory was suspended during the Confederate invasion in 1861-62, and after the Civil War mining was frequently interrupted by Indian raids (Lindgren, Graton, and Gordon, 1910, p. 18).

New ore discoveries in the 1860's and 1870's rekindled interest in mining in New Mexico. In 1865 gold placers were found in the Sierra Blanca in Lincoln County. The gold placers of Elizabethtown in Colfax County and silver-lead deposits at Magdalena in Socorro County both were found in 1866. In 1877 gold placers and gold-bearing quartz veins were found at Hillsboro, and in 1878 phenomenally rich silver ore was discovered at Lake Valley in Sierra County. Completion of the Southern Pacific and the Atchison, Topeka & Santa Fe Railroads through southern and central New Mexico from 1879 through 1882 stimulated development of many properties. The 1870's and 1880's were years of high silver production, but by the late 1890's, exhaustion of the rich oxidized ores and the financial depression of 1893 combined to reduce mining in the Territory to a low state of activity (Lindgren, Graton, and Gordon, 1910, p. 18, 19). The Mogollon district in Catron County was an outstanding exception to this trend and was the chief contributor of New Mexico's fairly high gold output in the 1890's (fig. 29).

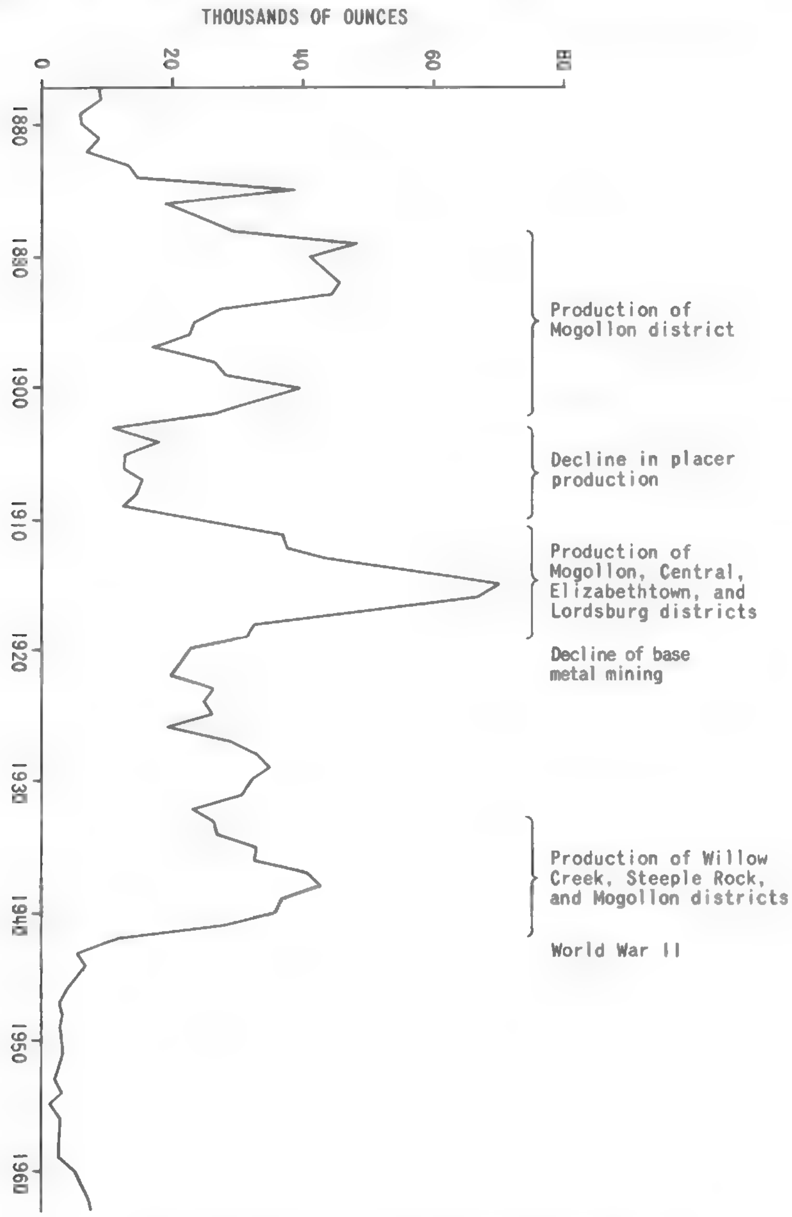

FIGURE 29.—Gold production in New Mexico, 1877–1963.

The rejuvenation of the mining industry in New Mexico and the other Western States began in the early 1900's with the development of new techniques of mining and milling, enabling the profitable exploitation of low-grade ores and extraction of byproducts. A new era of base-metal mining began, from which gold and silver were important byproducts. This relationship is noticeable in the contribution of byproduct gold from the large copper operations of the Central and Lordsburg districts to the high gold production of the State in the 1911-18 perid, and to the resultant decrease in gold output coincident with the decline in base-metal mining in the early 1920's (fig. 29) . In the early 1960's nearly all of the gold produced in New Mexico was a byproduct from the Central and Lordsburg districts.

PRODUCTION AND OUTLOOK

Faced with a gradual depletion of high-grade deposits and constantly increasing costs under a fixed selling price of $35 an ounce, the gold mining industry in the United States has been in a steady decline. From a high of more than 4.5 million ounces in 1940, production has dropped to 1.45 million ounces in 1963, a 6-percent decrease from 1962 and the lowest peacetime output in more than 100 years (U.S. Bureau of Mines Minerals Yearbook, preprint, 1964). The United States ranked fourth in world gold production in 1963. Production of gold throughout the world has been increasing. In 1963 a total of 51.7 million ounces was mined, an increase of 1.9 million ounces over 1962 and the 10th successive annual increase.

New Mexico is the 12th largest gold-producing State, with a total output of 2,251,014 ounces from 1848 through 1963. The State ranked 10th in 1963, when only 7,805 ounces were mined.

In general, gold mining in New Mexico has followed the national trend (fig. 29), and almost all gold currently produced is a byproduct of copper mining. The known placers and high-grade lodes are depleted, and at present no incentive exists to explore for new deposits. Under the present cost-price dilemma, gold production in New Mexico is dependent on the price fluctuations and production of copper. On the other hand the history of gold mining in New Mexico indicates that a favorable economic climate could support a fairly robust gold mining industry.

DISTRIBUTION AND TYPES OF DEPOSITS

The gold deposits of New Mexico are distributed in a belt of variable width that extends from Hidalgo County northeastward to Colfax County. This mineralized belt is a zone of crustal disturbance between the Colorado Plateau on the northwest and the Great Plains on the southeast. It is characterized by folded and faulted sedimentary rocks which are intruded by stocks, dikes, and laccoliths of monzonitic composition. A few deposits are Precambrian in age, but most are associated with Upper Cretaceous or Tertiary intrusive rocks.

The major gold deposits of New Mexico may be included under the following categories : fissue veins, replacement deposits, contact metasomatic deposits, and placers. In most districts several of the foregoing types occur; however, fissure veins have been the most promi-

nent source of gold. Seventeen mining districts in the State have produced a minimum total of 10,000 ounces of gold each (fig. 30). They are described in outline form in table 15.

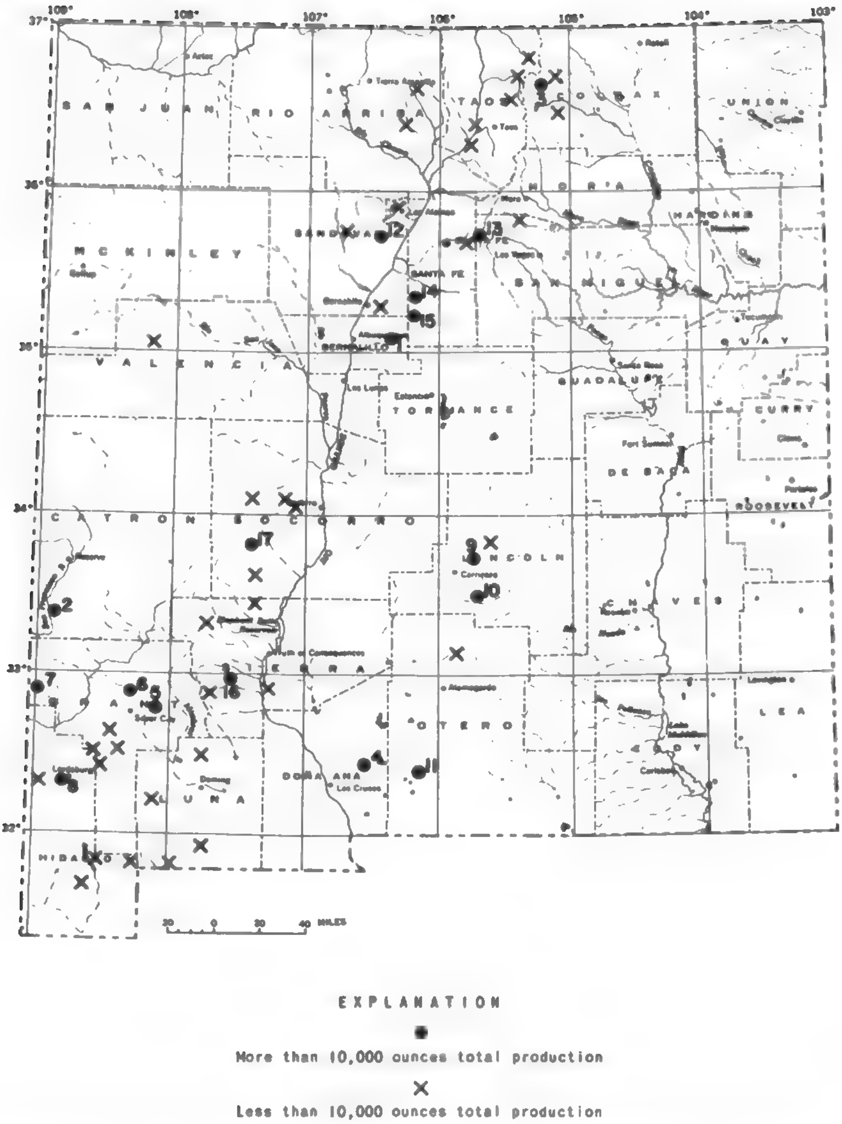

FIGURE 30.—Gold in New Mexico (numbers refer to districts listed in table 15).

TABLE 15.—*Major gold districts of New Mexico*

Map No.	District	Manner of occurrence	Gold production (ounces)	Remarks	References
		BERNALILLO COUNTY			
1	Tijeras Canyon	Fissure veins in Precambrian granite and metamorphic rocks.	34,500	Gold is byproduct of lead-silver ore	Ellis, 1922, p. 40–42.
		CATRON COUNTY			
2	Mogollon	Fissure veins in Tertiary volcanic and sedimentary rocks.	362,225	Size of ore bodies controlled by fracturing characteristics of wall rock rather than composition.	Ferguson, 1927, p. 5–50.
		COLFAX COUNTY			
3	Elizabethtown-Baldy.	Placers in stream gravels; stringers and veins in sedimentary rocks near dikes and sills of quartz monzonite porphyry.	221,400 lode; 146,980 placer.	Placers are near Elizabethtown; lodes near Baldy.	Lindgren, Graton, and Gordon, 1910, p. 92–97; Lee, 1916, p. 327–330; Chase and Muir, 1923, p. 272.
		DONA ANA COUNTY			
4	Organ	Veins in Precambrian rocks near a quartz monzonite batholith of probable Tertiary age.	11,435	Other deposits in district are veins and replacement deposits rich in copper, lead, silver, zinc.	Dunham, 1935.

TABLE 15.—*Major gold districts of New Mexico*—Continued

Map No.	District	Manner of occurrence	Gold production (ounces)	Remarks	References
		GRANT COUNTY			
5	Central	Contact metasomatic deposits in limestone (iron and zinc); veins related to quartz diorite and granodiorite intrusions (lead, zinc); disseminated copper deposits in granodiorite and intruded sedimentary rocks.	140,000	Gold is byproduct of base metal ores	Spencer and Paige, 1935; Lasky, 1936.
6	Pinos Altos	Placers in stream gravels; lodes in veins in Upper Cretaceous or Tertiary diorite and granodiorite bodies and in replacement deposits in limestone of Pennsylvanian age.	104,975 lode; 42,650 placer.	Gold is a byproduct of zinc-copper-silver ores.	Paige, 1911, p. 109–125.
7	Steeple Rock	Veins in volcanic rocks of probable Tertiary age.	135,000 minimum	Carlisle mine was chief producer	Lindgren, Graton, and Gordon, 1910, p. 327–328; Anderson, 1957, p. 76.
		HIDALGO COUNTY			
8	Lordsburg	Fissure viens associated with a late Cretaceous or early Tertiary granodiorite stock.	223,750 minimum	Gold is a byproduct of base metal ores.	Lasky, 1938.
		LINCOLN COUNTY			
9	White Oaks	Veins in a monzonite intrusive, lamprophyre dikes, and Cretaceous shale.	146,500	Small-scale placer activity in 1850's and 1860's.	Lindgren, Graton, and Gordon, 1910, p. 179–180; Jones, 1904, p. 172–175.
10	Nogal	Stringers and veins in monzonite porphyry and andesite, both of Late Cretaceous or Tertiary age.	12,850		Lindgren, Graton, and Gordon, 1910, p. 176–178.
		OTERO COUNTY			
11	Jarilla	Fracture zones in metamorphosed limestone of Carboniferous age; small placers.	16,500		Wells and Wootton, 1940, p. 14; Lindgren, Graton, and Gordon 1910, p. 185, 186.

			SANDOVAL COUNTY		
12	Cochiti	Veins in shattered and brecciated monzonite of probable Cretaceous age.	41,500	Some lodes are as much as 150 feet in width.	Lindgren, Graton, and Gordon, 1910, p. 150–162.
			SAN MIGUEL COUNTY		
13	Willow Creek	Mineralized shear zone in Precambrian schist. Ore is believed to be Precambrian in age.	178,300	Nearly entire output came from Pecos mine.	Krieger, 1932, p. 344, 364; Harley, 1940, p. 84; Lasky and Wootton, 1933, p. 93.
			SANTA FE COUNTY		
14	Old Placer-Cerrillos.	Richest placers mined from a mesa of gravel from an old alluvial fan. Small lodes in veins in monzonite of probable Late Cretaceous or Tertiary age and in contact metasomatic deposits in garnetized limestone.	99,300, mostly from placers.	Placers were discovered in 1828—earliest gold discovery in New Mexico.	Lindgren, Graton, and Gordon, 1910, p. 164–170.
15	New Placer	Placers in stream gravels and alluvial fans. Veins in Late Cretaceous or lower Tertiary porphyry and intruded Carboniferous formations. Copper-rich contact metasomatic deposits in roof of a laccolith; replacement deposits in limestone.	115,700, mostly from placers.	Placers were discovered in 1839	Lindgren, Graton, and Gordon, 1910, p. 170–175.
			SIERRA COUNTY		
16	Hillsboro	Placers in dissected alluvial fans; lodes in quartz veins along dikes of latite in Tertiary andesite.	149,000 (98,000 placer) (51,000 lode).		Harley, 1934, p. 125, 131–141, 166–169.
			SOCORRO COUNTY		
17	Rosedale	Veins in shear zones in rhyolite and rhyolite porphyry.	27,750	Rosedale mine was largest producer	Wells and Wootton, 1940, p. 19; Lasky, 1932, p. 95; Lindgren, Graton, and Gordon, 1910, p. 259–260.

Fissure veins

Fissure veins are mineralized fractures or faults in rocks of varied lithologic types and geologic ages. Prominent metallic minerals include pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, argentite, native gold, bornite, enargite, chalcocite, molybdenite, pyrrhotite, and arsenopyrite. Gangue minerals are quartz, calcite, fluorite, tourmaline, barite, and siderite. In the Mogollon district large amounts of gold and silver were mined from veins in a thick section of Tertiary lavas and pyroclastic rocks interbedded with small amounts of sandstone and conglomerate (Ferguson, 1927, p. 5-25). Veins also yielded considerable gold in the Elizabethtown-Baldy district, where the principal ore bodies were in pockets and stringers in the basal conglomeratic sandsone of the Raton Formation just above its unconformable contact with the underlying Pierre Shale of Cretaceous age. Some ore is in the upper part of the Pierre Shale. The sedimentary rocks are intruded by dikes and sills of quartz monzonite porphyry (Lee, 1916, p. 327-330).

Veins in the Lordsburg district yielded large amounts of gold and considerable silver as byproducts of ores mined chiefly for copper. The ore deposits are in faults that cut a granodiorite stock of Late Cretaceous or early Tertiary age and basalt of early Cretaceous age. The mineralization is thought to be related to the closing stages of intrusive activity (Lasky, 1938, p. 24) .

Other mining districts in New Mexico in which fissure veins have produced significant quantities of gold are Central, Pinos Altos, Steeple Rock, White Oaks, and Willow Creek.

Replacement deposits

Upward-migrating hydrothermal solutions sometimes encounter carbonate beds and replace the limestone or dolomite with sulfide minerals, some of which contain gold along with silver and base metals. These deposits are usually irregularly shaped and extend outward from fractures. The solutions are guided by fractures in, and porosity and chemical reactivity of the country rock. Common metallic minerals of replacement deposits are galena, pyrite, sphalerite, chalcopyrite, pyrrhotite, tetrahedrite, argentite, tennantite, enargite, and bornite. Gold is extremely fine-grained and usually occurs with pyrite. Gangue minerals are dolomite, quartz calcite, barite, and clay minerals. If these sulfide deposits are oxidized gold and silver are concentrated and the primary sulfides are transformed to sulfates and carbonates. Oxidized ore is usually rich in the precious metals.

Replacement deposits are important sources of lead, zinc, silver, and copper in New Mexico, but have yielded relatively little gold. The Pinos Altos and New Placer districts probably have been the most important sources of gold from replacement deposits.

Contact metasomatic deposits

Sedimentary rocks adjacent to intrusive rocks usually show some chemical and thermal effects of the igneous body. This alteration ranges from relatively inconspicuous baking or hardening to a thorough transformation of the invaded rock. In places contact metasomatic ore bodies are formed. This type of deposit has been a relatively unimportant source of gold in New Mexico. In the Old Placer district, gold was extracted from gold-bearing chalcopyrite in a garnetized limestone (Lindgren, Graton, and Gordon, 1910, p. 169-170). Copper-rich contact metasomatic deposits in the ew Placer district yielded gold and silver as byproducts (Lindgren, Graton, and Gordon, 1910, p. 173).

Placer deposits

Gold-bearing placers occur in stream aeposits, where the eroded gold has been concentrated by gravity through the action of moving water. Gold-bearing placers are scarce in New Mexico, the richer deposits were depleted by the early 1900's, and the lack of large volumes of water prevented any substantial mining of the lower grade deposits. The most productive placers were in the Old Placer, New i Placer, and Hillsboro districts, where the gold was concentrated in dissected alluvial fans and in the gravels deposited by streams that reworked the fans. Stream gravels were productive in the Jarilla, Pinos Altos, White Oaks, and Nogal districts.

SILVER

(By A. J. Thompson, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Silver is a white metal with a metallic luster, is ductile, very malleable, and has the highest thermal and electrical conductivity of any substance. Since it is not easily oxidized, it is included among the "noble" metals. This characteristic, coupled with its malleability and pleasing color, accounts for silver having been employed by prehistoric man in making simple ornaments or other articles. Its relative scarcity and its resistance to attack under ordinary atmospheric conditions has made it a desirable material for use in coinage. Until recent times coinage remained the principal use of the metal. An estimated one-third of the world output of silver is in circulation as coinage or is held by governments for monetary purposes.

In recent years silver has been increasingly used for industrial purposes. An outstanding example of such use has been photographic materials. Motion pictures and other forms of photographic reproduction may not have been possible without silver. Other major industrial uses include the fabrication of sterling tableware, electroplating, silver solders, and brazing alloys. Although not of great significance from the standpoint of the quantity consumed, silver has been important to man in the field of medicine; silver salts have long been used for the control of certain diseases and as an antiseptic and a germicide.

Although silver was widely mined and used in ancient and medieval times, its production was small compared to that which followed the discovery and development of rich deposits in the Americas after 1492. The world production of silver from 1492 to 1964 has been about 23 billion ounces. Of this total, about 80 percent was produced in the New World, North America contributing about 60 percent and South America contributing about 20 percent. Mexico produced about one-third of the world's total, the United States about 20 percent, and Peru and Bolivia about 9 percent each. Prior to 1919 the United States and Mexico alternated as the world's leading producer, but since 1919 Mexico has ranked first, in most years by a considerable margin. The United States contributed 29 percent of the world's silver in 1870, 40 percent in 1915, 25 percent in 1940, and about 15 percent in the period from 1960 to 1964.

In 1962 the total U.S. production of silver was 36.3 million ounces. Idaho, with a production of 17 million ounces, was by far the leading producing State. New Mexico, with a production of 282,000 ounces, ranked ninth (fig. 31) .

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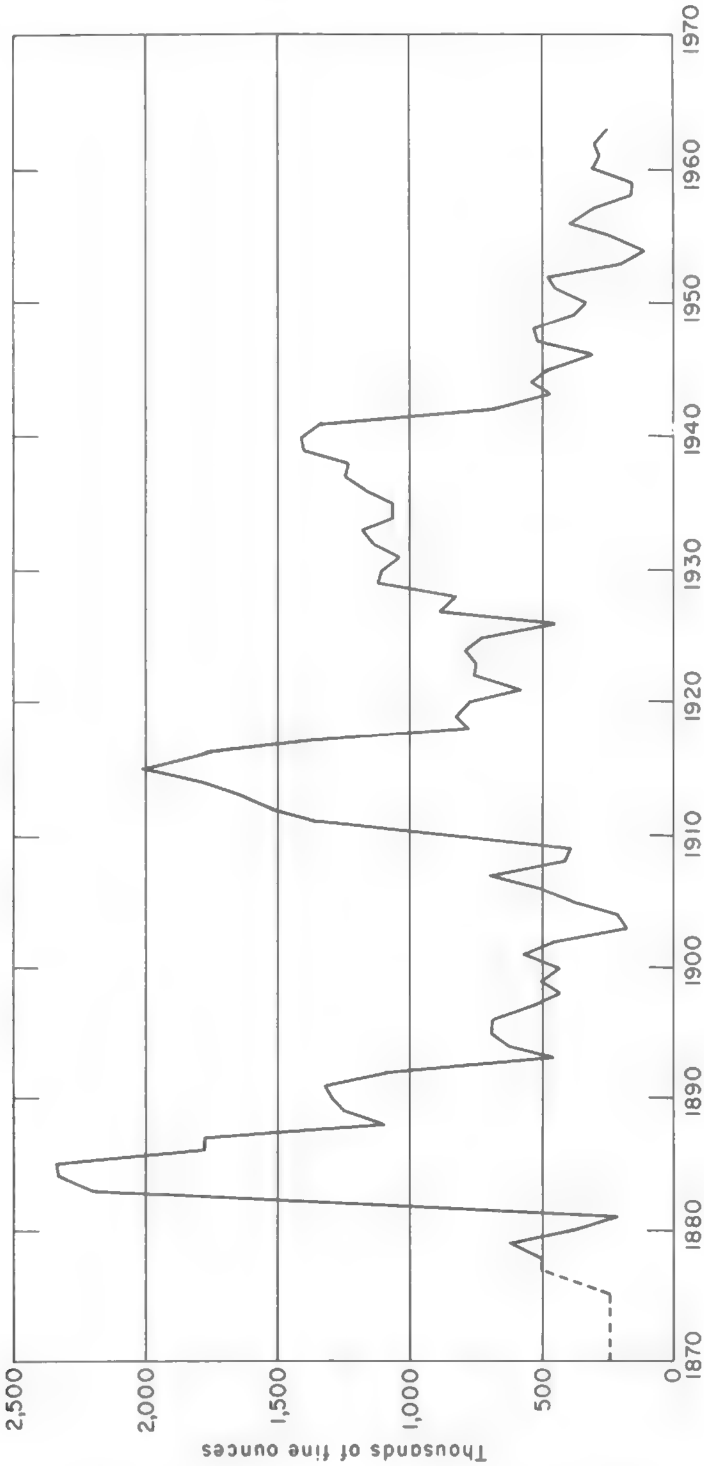
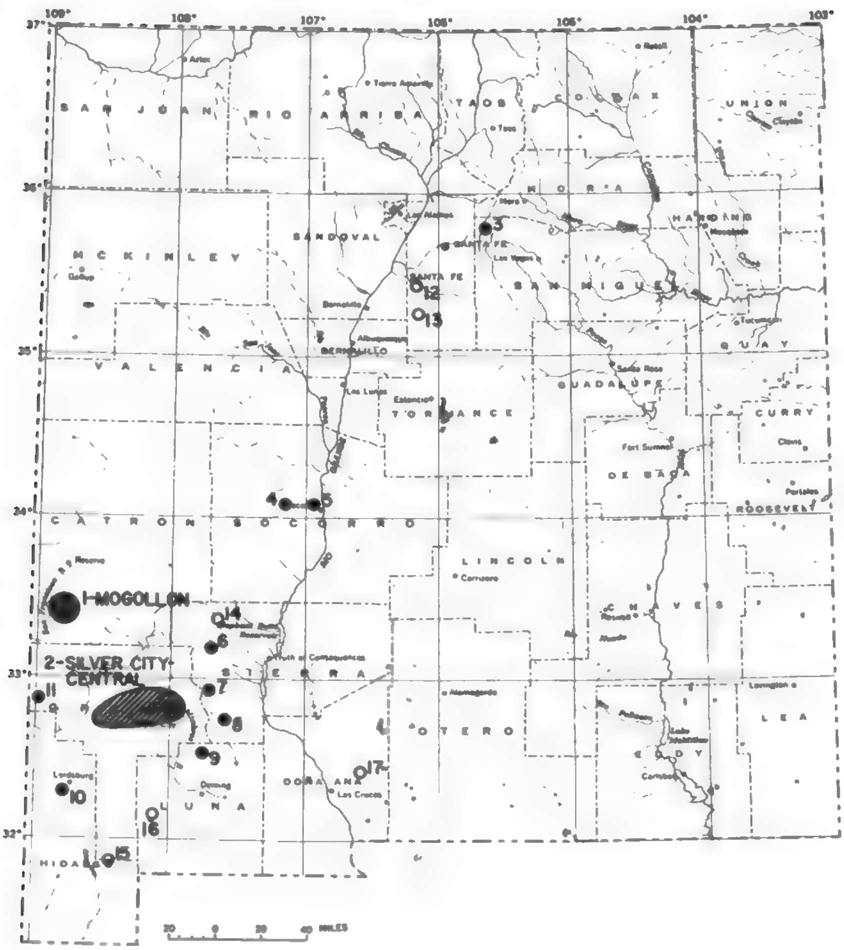


FIGURE 31.—Silver production in New Mexico, 1880–1963.

Silver in New Mexico has been found mainly in, or near, areas that have been important producers of base metals (figs. 32 and 33) . In many, if not most, base metal deposits silver occurs as argentiferous galena or as minute inclusions in other minerals. In these deposits silver ranges in amount from traces to ores in which silver is the most valuable constituent. Some factors that relate to the geologic distribution and occurrence of silver, as they pertain to deposits in New Mexico, are discussed in the chapter on lead in this report.

General history of silver mining in New Mexico.—There is evidence that some silver was mined in New Mexico in pre-Columbian times. However, the records are obscure and conflicting. Also, there is little evidence of any significant metal production during the period when the land that now is New Mexico was under Spanish or Mexican rule, except for copper mined at Santa Rita. For the period from 1848, the time of the first annexation of any part of New Mexico land to the United States, to 1880 no reliable figures on New Mexico's mineral production are available. However, data reported by U.S. Director of the Mint (1880, p. 158), indicate that New Mexico's silver production in this period may have been about 4 million ounces.

The first significant discovery of silver in New Mexico was made in 1863 at Pueblo Springs, near Magdalena, Socorro County. However, this discovery was not recognized at the time as an important find, nor did it soon result in any notable production of rich ore, so it did not spark a marked search for silver. Not until the silver ores at Georgetown were discovered in 1866, followed by an even richer find at Chloride Flat in 1871, did the importance of silver impress the early prospectors. The late 1870's and the decade of the 1880's comprised a period of great mining activity. The construction of railroads through New Mexico between 1879 and 1882 further stimulated the the search for mineral deposits. Practically all the precious- and the base-metal districts which later were worked had been discovered and developed by 1890. The epoch from 1880 to 1892 was essentially one of silver mining; copper and the other base metals were little sought and even gold received less consideration than silver. During those years the value of silver production in New Mexico was close to $20 million. Silver accounted for approximately two-thirds of the value of all the metals produced during this time interval. The main areas that were important as producers of silver are listed on table 16.



MAJOR AREAS	MINOR AREAS	OTHER AREAS
1. Mogollon	3. Pecos	12. Cerrillos
	4. Magdalena	13. San Pedro
2. Silver City - Central	5. Socorro	14. Cuchillo
	6. Hermosa	15. Hachita
	7. Kingston	16. Victorio
	8. Lake Valley	17. Organ
	9. Cooks Peak	
	10. Lordsburg	
	11. Steeple Rock	

FIGURE 32.—Silver in New Mexico.

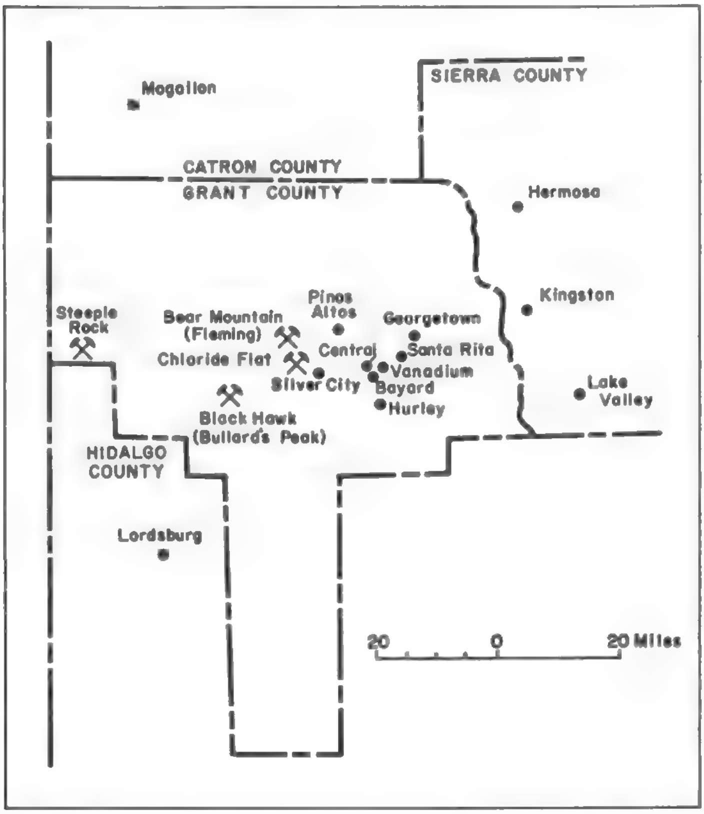


FIGURE 83.—Principal silver-producing areas in southwestern New Mexico.

TABLE 16.—*Silver-producing areas in New Mexico*

	Estimated production (ou[redacted]f silver)
Areas that produced silver as a major constituent of the ores:	
Mogollon	18, 000, 000
Silver City region:	
Chloride Flat	3, 300, 000
Georgetown	3, 500, 000
Black Hawk (Bullards Peak)	1, 000, 000
Fleming (Bear Mountain)	300, 000
Lake Valley	5, 500, 000
Kingston	6, 000, 000
Hermosa	1, 250, 000
Socorro	750, 000
Total	39, 600, 000
Areas that produced silver as a minor constituent of the ores:	
Ores of zinc and lead:	
Pecos	6, 200, 000
Bayard	6, 500, 000
Magdalena	4, 000, 000
Copper ores: Lordsburg	6, 000, 000
Gold ores:	
Steeple Rock	3, 000, 000
Pinos Altos	800, 000
Total	26, 500, 000

With the discontinuation in 1893 of Government purchase of silver, as provided by the Sherman Act, and the marked drop in the price which ensued, the silver boom in New Mexico ended. Some of the famous silver camps, including Lake Valley, Georgetown, and Chloride Flat, ceased to exist as mining camps of significance. Mogollon continued for another half century as the greatest single silver-producing camp in New Mexico.

Of the silver that has been produced in New Mexico, amounting to approximately 75 million ounces, about 60 percent has been from districts that have been largely or almost entirely silver-producing areas. Most of the remaining silver has been derived as a byproduct of the production of the base-metal ores, zinc, lead, and copper. A small percentage of the total silver mined has been associated with ores valuable chiefly because of their gold content.

Three mining districts that have yielded large amounts of byproduct silver have been outstanding in their output of lead and zinc as well. These are the Pecos in San Miguel County, the Bayard in Grant County, and the Magdalena in Socorro County (fig. 32) . Production in the Pecos district was relatively short lived, but the Bayard and the Magdalena districts have had few equals in years of production. Production from the Bayard district started nearly 100 years ago and still continues while the Magdalena district, although more sporadic in its mining activities, also has had about a century of mining history. Lordsburg, a fourth important producing area of byproduct silver, has been noteworthy for its copper also. Two gold mining camps, Steeple Rock and Pinos Altos, have provided an appreciable amount of silver.

Of the silver produced, prior to 1900, almost all was from silver ores. During the 40 years, 1900 to 1940, production was about equally divided between that derived from silver ores and that obtained as a byproduct from base-metal ores. During the last 20 years, byproduct silver from base-metal ores has accounted for 80 to 90 percent of the State's silver production.

The production of silver in New Mexico from 1848 to 1964 is summarized in table 17. The figures are given as a summary estimate for the years from 1848 to 1880 and for every fifth year thereafter, plus 1961 through 1963. A graph shows silver production in New Mexico from 1880 to 1963 (fig. 31) .

TABLE 17.—*Silver production in New Mexico, selected years 1848–1963*

Year	Ounces	Average price	Value
1848–79 [1]	4,000,000	$1.25	$5,000,000
1885	2,344,000	1.07	2,508,000
1890	1,300,000	1.05	1,365,000
1895	695,000	.65	452,000
1900	434,000	.62	269,000
1905	369,000	.61	225,000
1910	844,000	.54	456,000
1915	2,006,000	.51	1,017,000
1920	768,000	1.09	837,000
1925	735,000	.69	510,000
1930	1,107,000	.39	426,000
1935	1,062,000	.72	763,000
1940	1,408,000	.71	1,001,000
1945	465,000	.71	331,000
1950	339,000	.905	306,000
1955	251,000	.905	227,000
1960	304,000	.905	275,000
1961	283,000	.925	261,000
1962	302,000	1.084	327,000
1963	256,000	1.279	328,000
Total (1848–1963)	74,490,000		59,289,000

[1] Estimated.

DESCRIPTION OF IMPORTANT SILVER MINING AREAS

Mogollon district.—The Mogollon or Cooney mining district which has accounted for about one-quarter of New Mexico silver produced to date is located in a rugged mountainous section near the west edge of the State 75 miles northwest of Silver City.

Mogollon was one of the latest mining districts of the State to be exploited in spite of the fact that it is within 50 miles of the oldest mining area in the west, the area which includes the copper mines of Santa Rita. The Santa Rita mines were discovered and worked at a i profit 75 years before the first discovery of ore at Mogollon. It is noteworthy that the copper mines of Morenci, Arizona, 40 air miles to the west, had also been extensively exploited some years before the first Mogollon location. The delay in the discovery of the rich ores in the district is attributed to the inaccessibility of the area and to the presence of the Apache Indians who had established this remote region as their last bulwark against the whites.

The town of Mogollon was founded in the latter part of the 1880's. It was located in the canyon 3 miles south of another town called Cooney. The mines of the two camps were on an apparently related system of veins that occur in a series of faults and fissures in the volcanic rock which covers the area. Silver is associated with gold in the veins.

After Indian troubles had ceased, high transportation costs contributed to difficulties in mining exploitation. Freight costs for ore shipped to a smelter were about $50 a ton. Milling operations to concentrate the ore might cost about $10 a ton, and only from 50 to 60 percent of the gold and silver was recovered. Nevertheless, the district was credited by Jones (1904) with having produced, prior to 1904, $4,650,000 worth of metal, a large part of which was probably silver, the remainder being mostly gold.

The introduction of the cyanidation process in about 1905 marked the beginning of efficient and large-scale operations. Prior to that, for nearly a generation, the ores were treated by pan amalgamation and gravity concentration. The cyanidation process proved to be cheap and gave recoveries of about 90 percent of both gold and silver. From 1905 to 1926 the mines of Mogollon were practically in continuous operation, producing about $10 million worth of silver, about 60 percent of the total silver produced in the State during the period. Between 1926 and 1931, when new ore bodies were discoverd, the Mogollon district was inactive. The new ore bodies were of lower grade than those previously mined ; but, because of good management and increase in the price of gold, operations were successfully continued for 11 years, producing an additional $5 million worth of gold and silver, before the mines closed down at the beginning of World War II. Other operations, conducted during the years from 1943 to 1946, yielded another quarter of a million dollars worth of gold and silver.

Since 1946 there has been little mining activity in the Mogollon district. However, much territory remains unexplored in the vast vein systems, and it seems likely that much good ore awaits discovery.

Lake Valley.—According to Keyes (1908), the discovery of silver in the Lake Valley district was made in 1876 and the first production began 2 years later. After 1878 the mines at Lake Valley were worked almost continuously until August 1893.

The Lake Valley deposits were remarkable in their occurrence and richness. They occurred as cavity fillings and pipes in the Lake Valley Limestone of Mississsippian age. Lead, the base metal most commonly associated with silver, was present in such small amount that the ores by themselves were not suitable for treatment by smelting. This fact was determined by the mine owners after a smelter had been built at Lake Valley in 1882 and 1883 and had proved to be useless. Prior to the construction of the smelter an amalgamation mill of a type normally used to treat silver ores had been built to concentrate the silver, but had also proved to be useless. Another peculiarity of the Lake Valley deposits was the high manganese content of much of the ore, a fact which no doubt contributed to the difficulties encountered in attempts to concentrate the silver. During World War II and later, manganese ore was mined from Lake Valley claims and sold to the U.S. Government. The Lake Valley ores were distinctive in another way ; they contained an unusually high ratio of silver to gold, the ratio by weight being about 1,000 to 1.

Fortunately, most of the ores in the Lake Valley mines were so rich that concentration prior to shipping was not needed, and most of the silver from the district left the area as a high-grade product. Because of the richness of its ores, Lake Valley is the most celebrated of the New Mexico silver camps. In fact, one of the Lake Valley ore bodies, named the Bridal Chamber, has had few, if any, to equal it anywhere in the world in the richness of the silver masses it contained. Reportedly from one portion of the Chamber, having the dimensions of an average dining room, silver valued at more than a million dollars was obtained. It was reported that a single piece taken from the Chamber was worth $80,000. Enormous bodies of almost pure cerargyrite were mined at Lake Valley from 1880 to 1885. After 1885 low-grade ore was treated for a time in a silver-leaching plant. In 1893 with the drop in the price of silver, shipments from the area ended. Except for the manganese ores mined during World War II and in the middle 1950's the production from Lake Valley since 1893 has been small.

Saver City area.—Silver ore was discovered in the Chloride Flat district, 1 to 2 miles west and southwest of Silver City, in the spring of 1870. By 1881 (Engineering and Mining Journal, Oct. 15, 1881) the sale of bullion exceeded $1,250,000. Mining was from shallow openings, the greatest depth being 180 feet. The ore occurred in the form of silver chloride (cerargyrite) and native silver in fractures in the Fusselman Dolomite of Silurian age. In 1883, a railroad was completed to Silver City, allowing for the transportation into the area of more efficient mining, milling, and smelting equipment.

By 1893 the production of silver from the Chloride Flat mining district had attained a value close to $3 million. As was true for the other silver camps in the territory, the prosperity which this camp enjoyed ended in 1893, when the price of silver dropped below 70 cents an ounce. Some silver ore has been mined at various periods during the present century, but the total since 1893 has been relatively small. The estimated production of silver from Chloride Flat since mining first began is 3.5 million ounces.

Silver was discovered at Georgetown, 15 miles northeast of Silver City, in 1861, but commercial operations did not begin until about 1872. By 1875 the camp was booming, and deposits were being

worked in a mineral belt $2^1/_2$ miles to and 1 mile wide. Georgetown continued to be an important producer of silver until the drop in silver price in 1892 and 1893. The silver ore was chiefly silver chloride that was concentrated in pockets and fractures in limestone beds adjacent to dikes. The principal mines in the area were the Naiad Queen, Commercial, MacGregor, McNulty, and Satisfaction. Aocording to Jones (1904), the production of the Georgetown or Mimbres district amounted to $3.5 million. No mining activity of consequence has occurred there since 1893.

Another silver mining camp named Fleming was active in the Silver City area during the 1880's. Most of the Fleming production came from one mine, the Old Man, located on the south end of Treasure Mountain about 5 miles northwest of Silver City. The Old Man was discovered in 1882 and during the next 10 years produced silver ore valued at $200,000.

Kingston.—Kingston is on the east slope of the Black Range, 8 miles west of Hillsboro. It is the center of a mineralized zone which covers an area to the north, west, and south of the town. Roughly, the area is about 9 miles long in a north and south direction and about 4 miles wide. Ore in the mineralized zone occurs in pockets and pipes m limestone beds adjacent to dikes.

It is generally considered that silver was first discovered in Kingston in the fall of 1880. The discovery was followed by the organization of the Black Range mining district in the spring of 1881. However, not until 1883 was there any important production of silver ore. In the period from 1883 to 1904 the metal production credited to Kingston was valued at a little less than $6.3 million, nearly all of which was silver. Most of this production probably was achieved prior to 1893. There seems to be less evidence to substantiate the yield of silver credited to the Kingston area than is available to substantiate silver yields of other major producing camps in New Mexico. The estimated Kingston production—about 6 million ounces—may be considered as the maximum that might have been attained.

Since 1893 mining has been done only occasionally and on a small scale in the Kingston district. Probably a total of a few hundred thousand dollars would account for the production of metal from this camp since 1893, some from lead-zinc ores and some from ores valuable for their manganese content. There have been no important shipments of ore from the Kingston area in recent years.

Pecos.—The Pecos district is on the east side of the Pecos River Canyon at the mouth of Willow Creek, about 14 miles north of the town of Pecos, in San Miguel County. Ore was discovered in the area in the early 1880's, but there was no production until 1925.

The Pecos ore deposit was a complex mixture of zinc, lead, and copper sulfides containing minor amounts of gold and silver. It formed lenticular masses within a broad shear zone. The country rock consisted of Precambrian schists, diabase, granite, and related igneous rocks. The total output from the first production on January 2, 1927, to the last on May 31, 1939, was 2,299,082 dry tons of mined ore, containing 7,748,006 ounces of silver. The average price of silver during the period of operation of the Pecos mine was about 50 cents an ounce. In terms of the amount of silver produced, the Pecos mine has accounted for about 8 percent of the State's total, but in terms of

the value of the silver produced, it has accounted for only about 4 percent of that total. This remarkable mine was operated during a period when all the metals it produced except gold had to be sold at an extremely depressed price level.

Bayard.—The Bayard area comprises an 8- to 10-square-mile area directly east of Central in Grant County. It is part of the Central mining area, or district, which for many years has been an important and well-known producer of copper, zinc, and lead. The overall metal production of the Central district now has reached a value of more than a billion dollars. As a byproduct from this impressive base-metal production, about 9 million ounces of silver have been derived. Although nearly all the base-metal mines of the Central district have contributed to the total, the major portion of the silver production has come from a group of claims in the Bayard area (fig. 32). These claims, the San Jose, the Ground Hog, and the Lucky Bill, are adjoining claims on the same vein, near the town of Vanadium (see copper chapter). Since 1928 the three claims have been worked as a unit by the American Smelting & Refining Co., and are known as the Ground Hog operation.

The vein on the San Jose claim, according to one report, was discovered prior to 1870, and there was some production there during the 1860's. The Ground Hog and the Lucky Bill claims were located in 1900. However, important production from the three claims did not begin until 1928. Since that time the production has been well in excess of 5 million ounces of silver. The total alltime production from the Ground Hog, San Jose, and Lucky Bill claims probably is close to 6 million ounces. The deposits that contained the silver were mainly valuable because of their zinc, lead, and copper content, with zinc being the most important in terms of both weight and value.

Another large producer of base metals, chiefly zinc (see "Zinc" chapter) in the Bayard area has been the Bullfrog mine, of the U.S. Smelting & Refining Co., about 1 mile northwest of the eround Hog workings. The mine was operated rather intensively from 1943 to 1953. An estimated half million ounces of silver were recovered from the zinc-lead ores treated during that period.

Lordsburg district.—Mining near Lordsburg began in 1870, but not until early in this century did the area become an important metal producer. Copper has been the main product (see "Copper" chapter) although the gold and silver associated with the copper minerals have contributed greatly to the value of the ores.

From 1904 to 1935 the Lordsburg district yielded 1.6 million tons of ore containing 4 million ounces of silver. Ninety percent of this production came from one mine, the Eighty-Five, located a few miles southwest of Lordsburg. About one-half the ore from the Eighty-Five was produced during the period from 1920 to 1931, and amounted to about 750,000 tons having an average per ton assay of 1.23 ounces silver. It was shipped to Douglas, Ariz., for use as a siliceous flux in the Calumet and Arizona smelter. Earlier shipments of ore from the Eighty-Five mine averaged 3 ounces per ton silver. The Eighty-Five has produced little ore since 1932.

Since 1933 another copper mine in the region near the Eighty-Five, the Bonney-Miser's Chest 5 miles south of Lordsburg, has yielded a substantial amount of byproduct silver. In recent years, in addition to the Bonney-Miser's Chest mines, a significant output of copper ore

containing byproduct silver has come from the Atwood and the Henry Clay mines, which adjoin the Eighty-Five. In total, the byproduct silver from the copper mines near Lordsburg has probably amounted to about 6 million ounces.

Future possibilities.—There still remains in New Mexico as established ore bodies a large tonnage of base-metal ores that are known to contain varying amounts of byproduct silver. Silver production from such ore no doubt will continue at a rate that should equal or exceed that of recent years. Also, it can reasonably be assumed that there remain in the State base-metal ore bodies that future exploration will uncover and that will in time add substantially to byproduct silver production.

The discovery of ore deposits in which the value lies largely in silver is less certain. All indications point, however, to a marked increase in exploration for silver in the coming years occasioned by the sharp rise in the price of silver that has taken place over the last 2 years. The 1964 silver price of 129.3 cents an ounce is the highest since the 1870's. Many established mining companies and others are beginning or planning a search for silver deposits. New Mexico can be expected to share in these activities and to share as well in the discovery and development of silver deposits that may result from such work. At present, certain areas stand out as being especially favorable for exploration in New Mexico. Ranking first among these is the region comprising the old Black Range and Apache (Chloride) districts, which includes an area of nearly 350 square miles. It extends from above the north boundary of Sierra County southward along the east slope of the Black Range for a distance of 30 or more miles. No appreciable amount of exploration at depth has been conducted in the area, nor is it believed that all possibilities near the surface have been exhausted. As the geology of the region becomes better understood more promising prospects can be drilled and otherwise examined by conventional, or yet-to-be-developed exploration methods. It can be hoped that silver production in this area will again play an important role in the region's economy. Other regions of the State, such as the mineralized belts of Grant, Hidalgo, Socorro, and Lincoln Counties, also may hope to benefit by the knowledge gained from more extensive and detailed geologic studies and from the application of new exploration techniques in the search for ore bodies.

LEAD

(By A. J. Thompson, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Lead is one of the most important industrial nonferrous metals used in its metallic form ; it is important also in its use in compounds and for the properties that it imparts to its alloys. Of the lead consumed in 1963, about 70 percent was used in metal products, the major item being storage batteries, which accounted for 33 percent of all lead consumed. Consumption in oil refining and as a gasoline additive accounted for 18 percent of the total, and manufacture of pigments required 9 percent.

Mines in the United States produced 251,000 short tons of recoverable lead in 1963; this was 9 percent of the world's total. The four

largest lead producing States were Idaho, Missouri, Utah, and Colorado. New Mexico ranked 13th among the States.

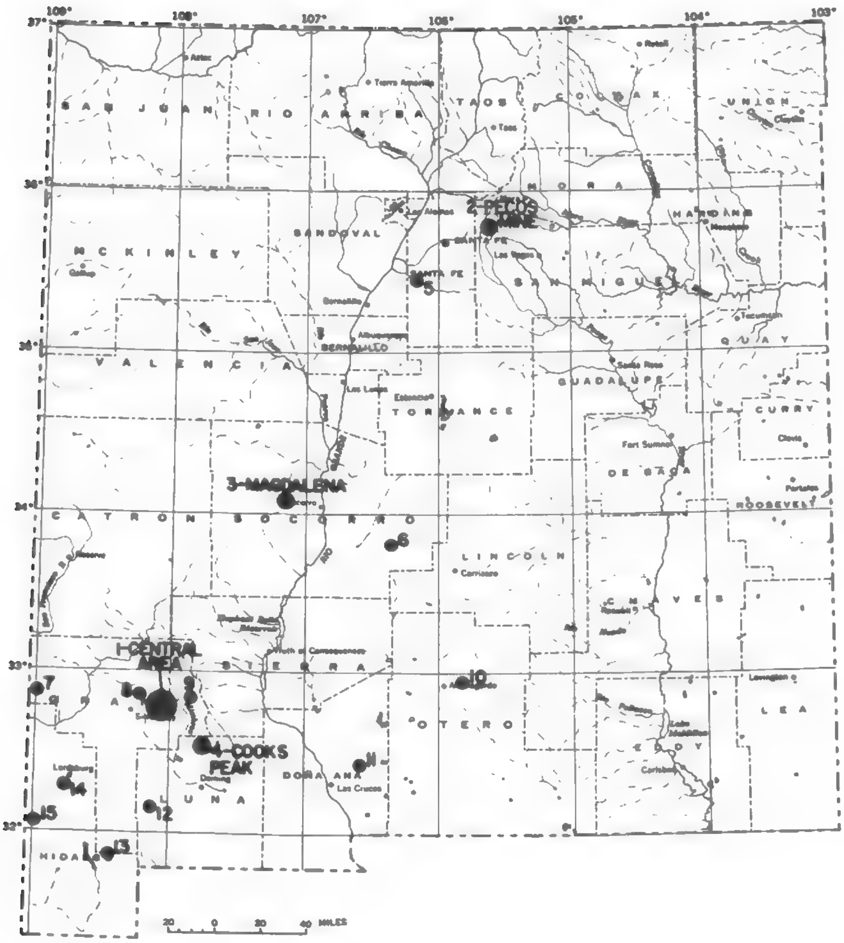
The lead and zinc deposits in New Mexico occur in a zone of a long-continued igneous activity, in an area that is for the most part less than 100 miles wide, and which extends from the southwest corner of the State to the Colorado border in the north-central part of the State (fig. 34) . This zone in a general way is bordered on the northwest by the Colorado Plateau and on the southeast and east by the Great Plains. The ore bodies are associated with intrusive masses of acidic or intermediate composition as well as with basic dikes. The deposits generally are found in the rocks bordering the intrusives but may occur in the intrusive rocks as well. The ores which have been mined occur as irregular replacement deposits, usually in upper Paleozoic limestones; as irregular contact deposits along the boundaries between intrusive rocks and limestones of any age • or in wide shear zones, stringer leads and lenticular bodies, both in intrusive rock and in Precambrian schists. The most abundant deposits are those that were formed at the end of Cretaceous or during earliest Tertiary time. An important exception is the Precambrian deposit of the Pecos mine.

Galena is the commonly occurring lead mineral and the one normally formed in primary mineral deposits in New Mexico. In the early mining days, however, the chief lead minerals were lead carbonate (cerussite) and lead sulfate (anglesite), formed from the oxidation of galena. The weathering of mineral deposits, which results in the oxidation of sulfide minerals, takes place above the water table. In the case of lead sulfide the conversion to various oxidized minerals usually takes place without appreciable migration of the lead. On the other hand, zinc and other soluble minerals react quite differently from lead during oxidation. Zinc is converted to soluble compounds, usually zinc carbonate, and is removed by percolating waters from the oxidized zone. The removal of the zinc, a common component of western lead deposits, and the removal of other soluble minerals by percolating waters, produces concentrations of oxidized lead ores in the higher levels of the primary deposits. Oxidized ores, enriched in lead, commonly are enriched in silver as well. Such ores were a source of much of the silver and the lead mined in New Mexico in the past.

The first authenticated production of lead in New Mexico was in the Organ Mountains in Dona Ana County, at the Stevenson mine. The Stevenson ore body was discovered in 1849 and during the following 10 years produced about $100,000 worth of silver and lead. The ore was mined mainly for its silver content and most of the lead was wasted except as needed in the silver recovery process.

Prior to 1900 the production of lead ores in New Mexico mainly was as silver-bearing lead bullion, the lead being required in the conventional smelting operation then employed to collect and concentrate the silver. Silver often is associated with lead minerals in New Mexico ores, and enough lead normally was present in the ores mined in the early days to allow for the proper concentration of the silver. When the silver ores did not contain enough lead, ores low in silver but high in lead were mined and used in the treatment process.

Since 1900 the record of lead mining in New Mexico to a large degree is a record of production of lead-zinc ores in which lead in most cases has been a minor constituent. In view of the role that lead has played



MAJOR AREAS
1. Central
2. Pecos mine
3. Magdalena

MINOR AREAS
4. Cooks Peak
5. Cerrillos
6. Hansonburg
7. Steeple Rock
8. Pinos Altos
9. Swartz
10. High Rolls
11. Organ Mountains
12. Victorio Mountains
13. Hachita
14. Lordsburg
15. San Simon

FIGURE 34. Lead in New Mexico.

as a component of ores in which silver or zinc was the metal of primary importance, it is not surprising that the value of lead production in New Mexico has been exceeded by that of the other two metals. The estimated alltime values of zinc, silver, lead, copper, and gold produced in New Mexico through 1963 is as follows :

Copper	$1,070,000,000
Zinc	240,500,000
Silver	60,000,000
Gold	58,000,000
Lead	48,000,000

The total production of lead in New Mexico has amounted to about 337,500 short tons. In table 18 is presented the distribution of this production according to the counties from which the ore was mined.

TABLE 18.—*Lead production in New Mexico by counties 1848–1963*

County	*Short tons*
Grant	152,500
Socorro	73,000
San Miguel	67,000
Dona Ana	12,500
Luna	7,600
Hidalgo	7,300
Santa Fe	6,800
Sierra	6,100
All other	4,700
Total	337,500

Three counties have dominated the mining of lead in New Mexico: Grant, Socorro, and San Miguel. One area in each of these counties has accounted for the bulk of the production from that county; the Central area in Grant County, the Magdalena district in Socorro County, and the Pecos district in San Miguel County. Mines that have been outstanding as lead suppliers are the Ground Hog—San Jose operation at Vanadium in the Bayard district, Grant County (fig. 34) ; the Pecos mine in San Miguel County ; and the Kelly-Graphic-Waldo group of claims in the Magdalena Mountains, Socorro County. Available records indicate that these three mining units together have produced well over one-half of the total lead mined to date in New Mexico. These mines have been large producers of zinc as well. Figure 35 summarizes total lead production in New Mexico.

The important lead-producing districts and mines in Grant, Socorro, and San Miguel Counties are described in the sections under "Silver" and "Zinc." An exception is the Cooks Peak region in Grant County which is noteworthy in that its production has been largely in lead, this metal accounting for 80 percent or more of the total value of the material mined. The Cooks Peak district is on the north side of Cooks Peak, the highest mountain of the range north of Deming. Oxidized lead ore was discovered at Cooks Peak about 1876, but the important deposits were not located until 1880. The oxidized ores were particularly desired by the smelters, and the district was very active for some time. Production up to 1910 has been valued at about $3 million, of which four-fifths represents lead and one-fifth silver. There have been several periods of activity in the area since 1908, but the mineral production during these periods has been relatively small. The total production of lead from the Cooks Peak district from the

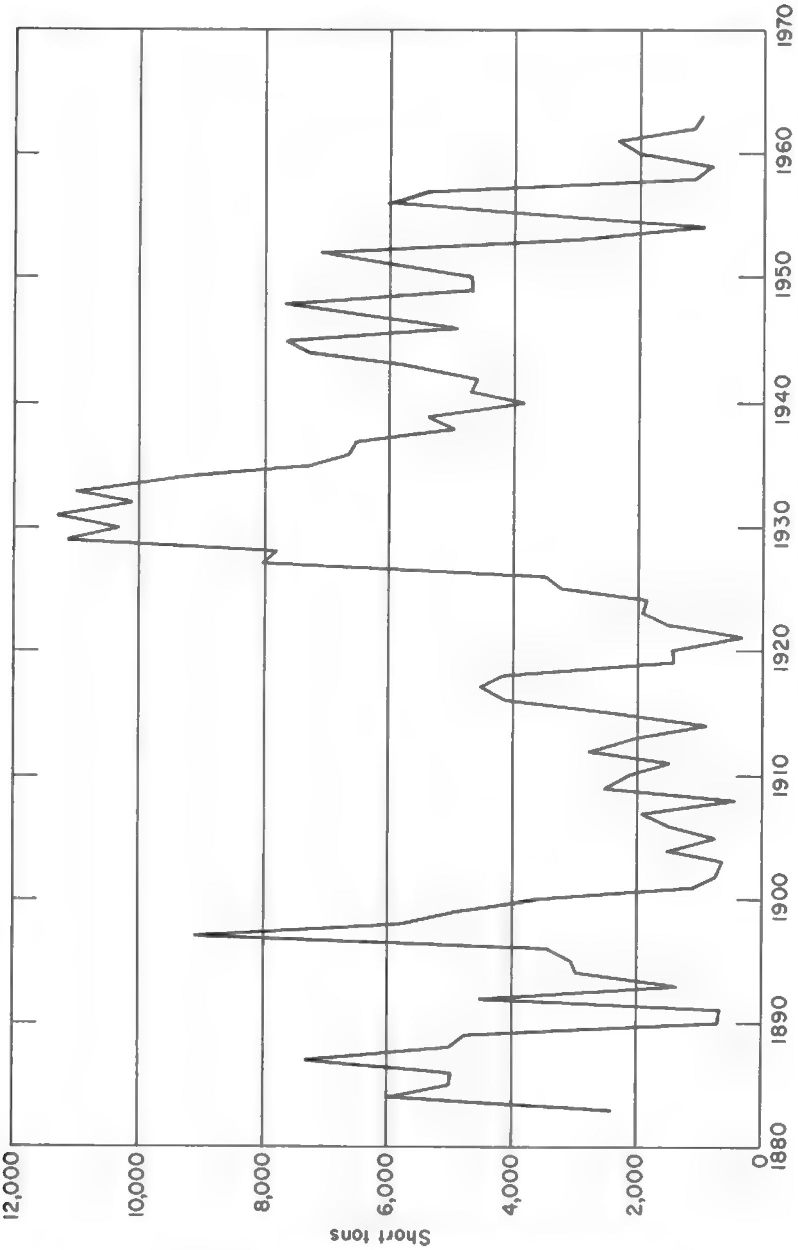


FIGURE 35.—Lead production in New Mexico.

time of ore discovery in 1876 is estimated to be approximately 50 million pounds or about 7 percent of the State's total production.

In Dona Ana County, the production of lead has come almost entirely from the Organ district and the major part of this production has been from the Stevenson-Bennett mine. The operation of this mine may be divided into three periods. The first, lasting from the time of its discovery in 1819 until 1882, was occupied by the mining of the Stevenson ore body, which cropped out at the surface. The mining methods employed were crude and it is said that all the ore removed during this period was carried out of the open stope on the backs of laborers. The ore, which was silver-bearing lead, was smelted in an adobe furnace near the Rio Grande. The second period began with the discovery of a new ore body called the Bennett, which proved to be larger than the Stevenson although less rich in silver. The Stevenson-Bennett mine, during this second period (1882-90), became an important producer of lead as well as silver. The third period of major acitvity began in 1908 after considerable exploration work had been performed and a mill to treat 300 tons of ore per day was put in operation. Activities in the Stevenson-Bennett mine between 1908 and 1920 accounted for a large part of the mine's total production. There has been no appreciable production from the Stevenson-Bennett mine since 1920.

Another important lead producer in the Organ Mountain district was the Modoc mine. It is at the south end of a fault zone which contains the Stevenson-Bennett ore bodies. The production from the Modoc, estimated to be as high as $200,000 in value, was almost entirely in lead. The period of activity was from 1879 to 1905.

Although reliable estimates of unmined lead in New Mexico are not generally available, evidence indicates that important reserves of this metal still remain, entirely apart from the possibilities of new discoveries, the prospects for which seem bright in certain places. Favorable areas for such new discoveries in general correspond to those for zinc and silver and are mentioned in the sections devoted to these metals. From the standpoint of reserves, New Mexico probably is in a good position to remain a significant producer of lead.

ZINC

(By A. J. Thompson, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Zinc ranks fourth in tonnage among the metals produced in the United States, being outranked only by iron, aluminum, and copper. It is indispensable to the industrial strength of the United States, for the production of an extremely wide range of military and essential civilian goods. Galvanizing and diecasting have absorbed about three-fourths of the zinc metal produced in recent years ; metallic zinc also is used in the manufacture of brass and other copper alloys. Zinc oxide is an important constituent of certain types of rubber, and other zinc compounds are employed in paints and chemicals.

The United States gets its zinc from both domestic and foreign sources. In recent years the supply from these sources has been in about a 1:1 ratio. The United States for many years has been the

largest zinc-producing country in the world, with an output of about one-seventh of the total ore and about one-quarter of the total refined metal.

The total production of zinc in New Mexico, amounting to about 2.6 billion pounds with a value of $240 million, places zinc as the sixth most important mineral commodity the State has produced to date. In total value of production, zinc is exceeded only by petroleum products, potash, copper, uranium, and coal. New Mexico's ranking among the States in recent years has varied from 7th to 15th. Zinc production is summarized in figure 36.

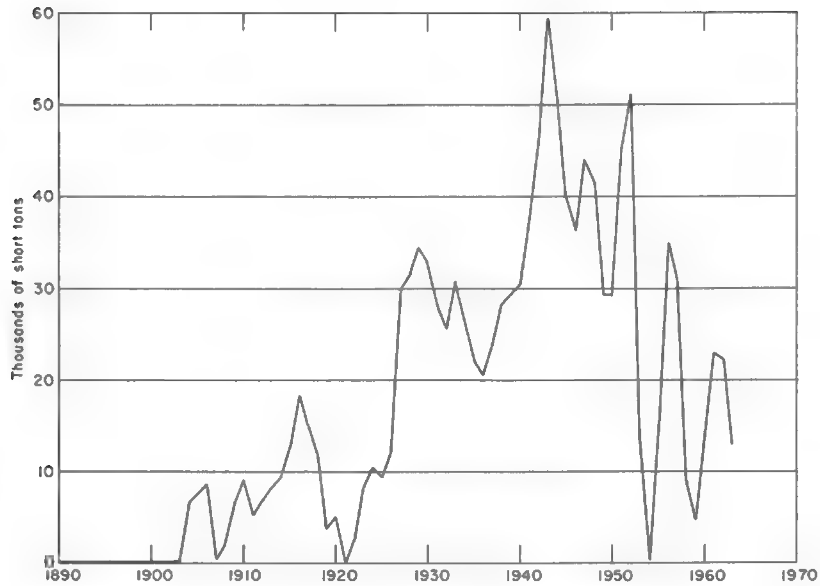
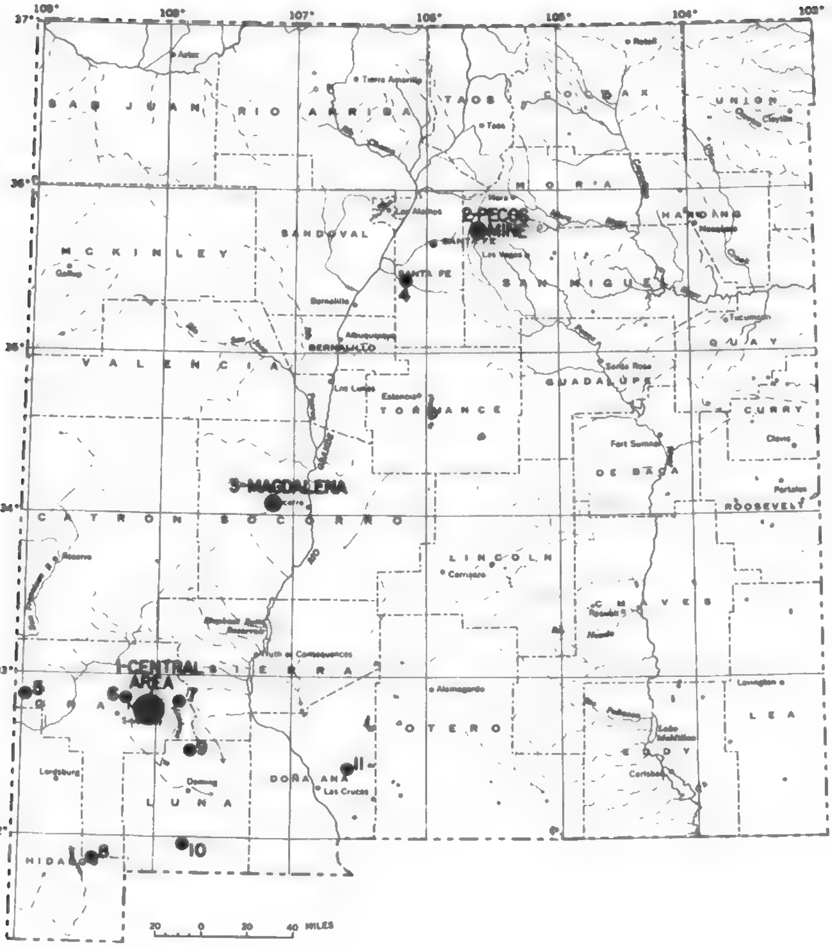


FIGURE 36.—Zinc production in New Mexico, 1890–1963.

Almost all of the zinc mined in New Mexico has come from Grant, Socorro, and San Miguel Counties (fig. 37) . Zinc deposits in New Mexico are of two types : they occur as replacements in limestone beds and as vein deposits.

GRANT COUNTY

Records indicate that mining of zinc ore in New Mexico began in the early 1890's, from deposits east of Silver City, about 90 years after the first commercial production of copper. Although the deposits had been known for many years, not until the Atchison, Topeka & Santa Fe Railway reached the area in 1891 did it become economically feasible to mine zinc. Production proceeded slowly at first and remained relatively small ; the production of 1,285,500 pounds in 1910 probably exceeded the previous total. Grant County, by late 1964, had yielded more than 900,000 short tons of zinc, and more than two-thirds of the total for New Mexico (table 19; fig. 38).



MAJOR AREAS

1. Central
2. Pecos
3. Magdalena

MINOR AREAS

4. Cerrillos
5. Steeple Rock
6. Pinos Altos
7. Swartz
8. Hachita
9. Cooks Peak
10. Tres Hermanas
11. Organ Mountains

FIGURE 37.—Zinc in New Mexico.

TABLE 19.—*Zinc production in New Mexico, 1904–63*

County	Production (in pounds)
Grant	1, 755, 633, 000
San Miguel	504, 825, 000
Socorro	324, 609, 800
Luna	9, 066, 000
Santa Fe	5, 962, 700
Dona Ana	1, 693, 500
Hidalgo	1, 176, 000
Sierra	648, 300
Lincoln	20, 000
Total, New Mexico	2, 603, 700, 000

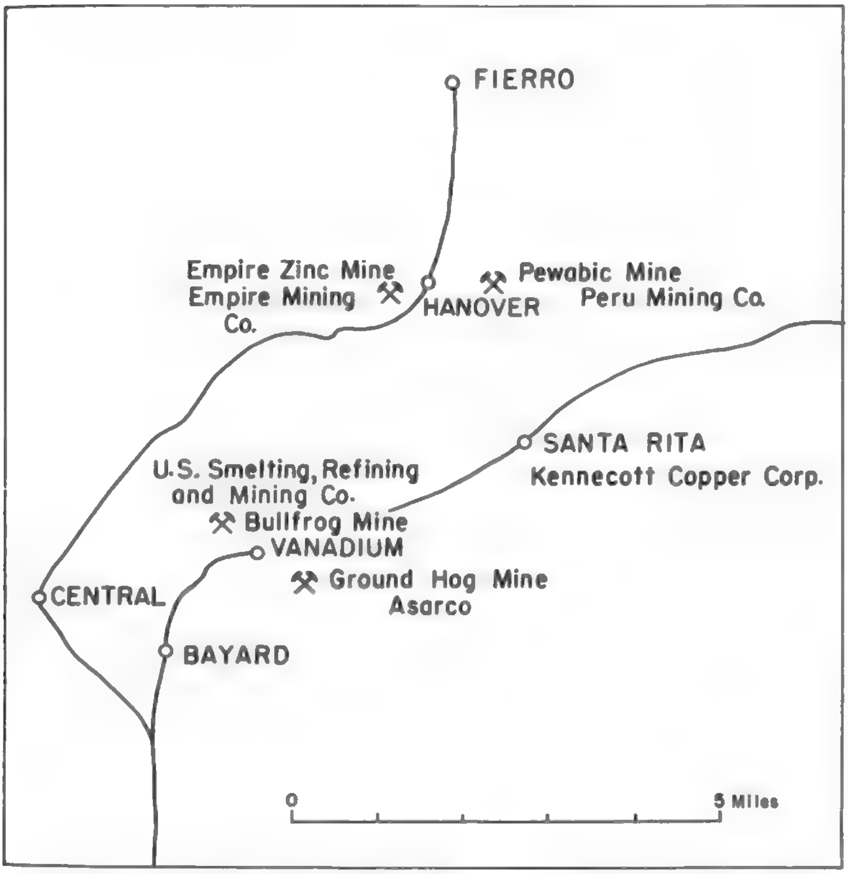


FIGURE 38.—Principal zinc-producing mines in the Central district, Grant County, N. Mex.

The Empire zinc mines at Hanover have dominated zinc mining in New Mexico. These mines have been operating since 1902 except for several periods when the demand for zinc was low. The mines at Hanover were distinctive in another way ; for about 30 years, beginning in the early 1920's, mules served as the power source for all underground hauling. In spite of stiff competition from newly developed trolley systems and battery locomotives, the mules held tenaciously j to their jobs.

Since 1928 the Pewabic mine, about half a mile east of the town of Hanover, yielded approximately 400 million pounds of zinc valued at $25 to $30 million. Zinc has been essentially the only metal produced by the Pewabic mine; most other zinc-producing mines in the State yield substantial amounts of lead as well.

The Bullfrog mine, which was first known as the Owl mine, was worked on a small scale prior to 1905, but remained idle from 1905 until 1940. In March 1943, after a period of exploration, mining was resumed. The ore is milled in a 600-ton concentrator. Zinc and lead have been the chief metals produced, with minor amounts of copper, silver, and gold. This mine, along with nearby smaller mines, was the leading supplier of zinc in the State for a number of years during the 1940's and 1950's. The total zinc production has probably amounted to several hundred million pounds.

The Ground Hog mine, about half a mile southeast of the town of Vanadium, has been in operation since 1928, and was the leading producer of zinc in New Mexico during 1955 and 1956. Although the mine has yielded a considerable amount of lead and copper, from the standpoint of tonnage zinc has been the most important metal mined.

SOCORRO COUNTY

Although the first recorded production of zinc in New Mexico was in Grant County in the early 1890's mining in quantity did not begin until the realization in 1903 and 1904 that massive deposits of zinc carbonate, an oxidized zinc ore found in Magdalena, were valuable for use in paint manufacture. For many years prior to 1900 the mines in the Magdalena area had been important producers of gold, silver, and lead, and large quantities of zinc carbonate, whether recognized or riot, had been removed as waste and thrown over the dump. In 1903, a discovery was made of especially rich zinc carbonate ore bodies as replacements in limestone. An attempt followed to find a market for the ore and samples were taken to the Joplin, Mo., smelter; it was determined that the material was suitable for the manufacture of zinc pigment, and large bodies of zinc carbonate ore began to be worked in the two important mines of the Magdalena area, the Kelly and the Graphic mines. The Graphic and the Waldo mine were major producers of zinc ore in the area until June 1949. Production was high throughout the period of World II. Ore from the Kelly, Lynchburg, and other mines has added substantially to the zinc output of the district.

From 1903 to 1930 zinc was the principal metal produced in the Magdalena district, and nearly half of the zinc produced in the State, valued at about $16 million, came from this district. In the earlier

years the zinc carbonate, smithsonite, constituted most of the production. The mining of zinc carbonate soon gave way to the production of the sulfide mineral sphalerite; and this mineral has been the chief zinc mineral mined in Magdalena, and elsewhere in New Mexico. Some of the smithsonite found in Magdalena contains a small amount of copper which gives it an unusually attractive green or greenish-blue shade, so that, whether polished or unpolished, it is prized as a semigemstone (see "Gems" chapter).

Since 1930 zinc mining in the Magdalena area has followed the pattern of other zinc camps in the West; production fluctuates with prices. The total production of the area is estimated at 325 million pounds.

SAN MIGUEL COUNTY

San Miguel County ranks next to Grant in production of zinc ; all of it came from the Pecos mine during 12 years of intensive operation. At the junction of Willow Creek and the Pecos River there is a copper-stained silicified outcrop that has been known since 1878. A number of mining locations were made on the deposit, and a considerable amount of development work was performed. The high-grade zinc and lead ore that was revealed under the outcropping proved, however, to be refractory to normal concentration procedures, and it was not until the 1920's that a satisfactory operation on this deposit seemed assured. In 1925 a 600-ton flotation mill was built to treat the mine ore. The mill began operation in January 1927 and operated continuously from the time it was first set in motion, except for normal shutdowns for repairs, until its final closing in May 1939.

Records indicate that the Pecos mine produced a total of 2,299,082 dry tons of ore, containing 243,474 ounces of gold, 7,748,006 ounces of silver, 185,514,389 pounds of lead, 35,835,807 pounds of copper, and 595,355,840 pounds of zinc. The reported recovery of zinc in the milling operation was 504,824,696 pounds. It is interesting to note that the Pecos mine operated throughout the depression years, when the price of zinc reached the 20th-century low figure of 2.9 cents a pound and the average price probably less than 5 cents.

Although Grant, Socorro, and San Miguel have been the chief zinc-producing counties, other counties have made significant contributions to the total. Table 19 lists New Mexico zinc production by counties during the last 60 years.

THE FUTURE OF ZINC IN NEW MEXICO

Present estimates indicate that there may be about three-quarters of a million tons of unmined zinc in New Mexico. The reserves of the Central district in Grant County, the area most studied to date, account for the major part of this estimate. Other regions with significant potential are in Socorro, Sierra, Santa Fe, Luna, Hidalgo, Otero, and Catron Counties. Basic geologic studies now in progress, and exploration work using modern or yet-to-be-developed techniques, could markedly expand the presently known resources.

COPPER

(By W. R. Jones, U.S. Geological Survey, Denver, Colo.)

Copper is one of the most important and most indispensable of the nonferrous metals. In tonnage and value of metals produced in the United States, copper is surpassed only by iron and aluminum. It has high electrical conductivity and is used mainly to transmit electrical energy—it has made the "age of electricity" possible. In addition, copper has high heat conductivity, tensile strength, ductility, malleability, and resistance to corrosion in most solutions. It has a pleasing color, is nonmagnetic, and can be plated, lacquered, welded, brazed, and soldered. Alloying with tin to form bronze and with zinc to form brass improves certain of its more desirable properties. A little more than half of the copper consumed is used m virtually the pure metallic state by the electrical industry in manufacturing generators, motors, electronic equipment, and wire for transmitting energy and communications. Most of the rest is used in the production of alloys. Aluminum, stainless steel, and plastics are being substituted for copper in Some uses.

The world production of copper from ores in 1962 totaled about 5 million short tons, of which the United States produced about one-quarter. Domestic consumption, however, slightly exceeded domestic production plus copper recovered from scrap, so the United States was partly dependent on copper imports. The average domestic price of refined copper in 1962 was about $0.31 a pound. Copper prices fluctuate moderately with demand, and the world and domestic production respond to some extent to price changes (fig. 39) .

GEOLOGIC OCCURRENCE

A trace of copper occurs as an original constituent in most types of rock that form the crust of the earth, which has an average copper content of about 55 parts per million (0.0055 percent). Granitic rocks average about 10 parts per million in copper and basaltic rocks about 100 parts per million (Taylor, 1964). The copper content of sandstone and limestone, like that of granite, is generally low, whereas shale commonly contains as much as the average basalt. In these rocks part of this copper occurs in the crystal structure of the rock-forming minerals and part occurs as minute grains of copper sulfides and native copper.

Commercial copper deposits represent local concentrations greater than 100 times the average copper content of the crust; these local concentrations are the result of certain geologic processes. Most deposits were formed in rocks near the surface of the earth by precipitation of copper minerals from hot solutions rising from deep-seated bodies of magma. Precipitation occurred either in open spaces in the rocks or by replacement of other rocks or minerals. In some deposits the ore minerals are rather uniformly distributed through large masses of intensively fractured rock; these are called disseminated deposits. They usually form in igneous rock and are commonly of low grade, some containing less than 1 percent copper. These may be exploited profitably because of their large size and because they lie near the surface and can be mined by low-cost open-pit methods. Vein deposits are formed along conspicuous fractures that served as principal chan-

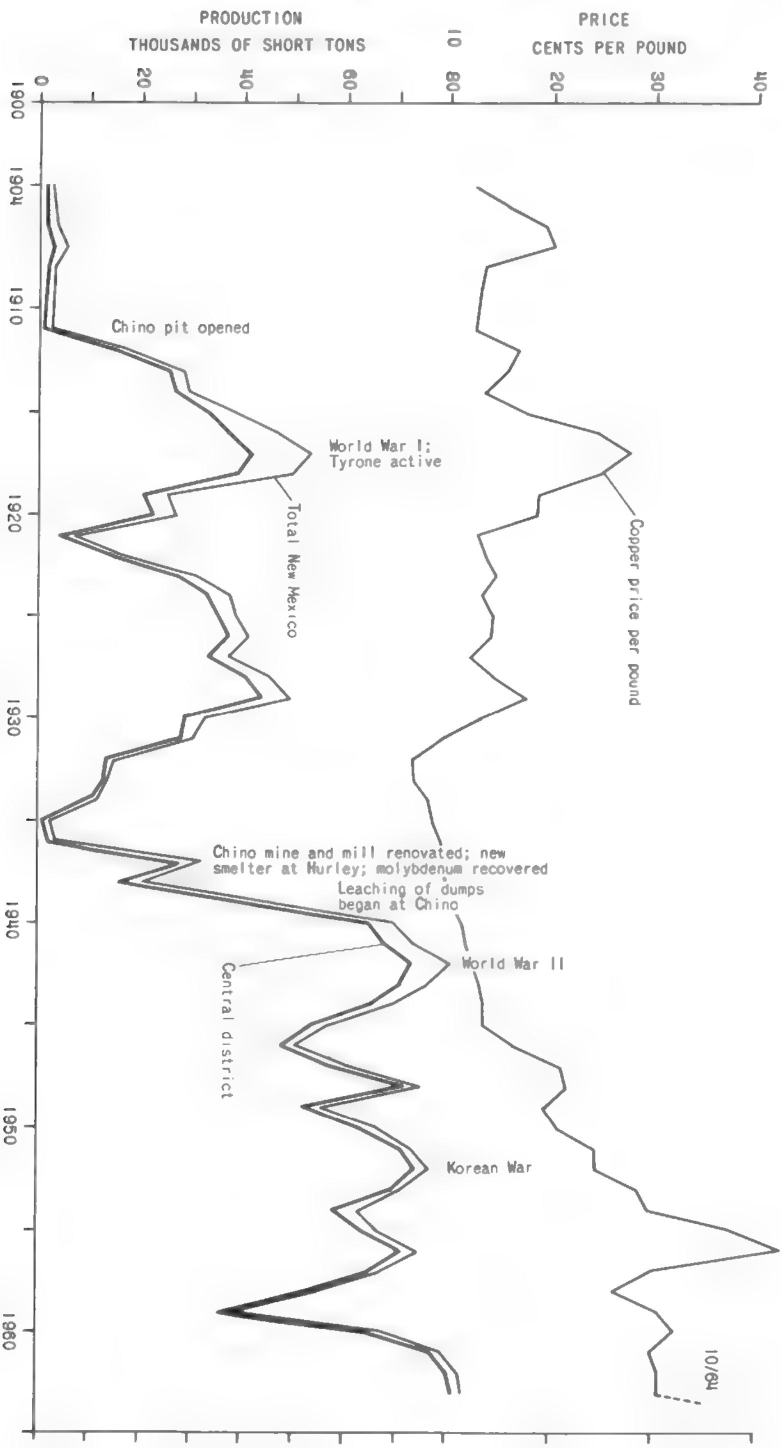


FIGURE 39.—Trends in price of copper and copper production in New Mexico.

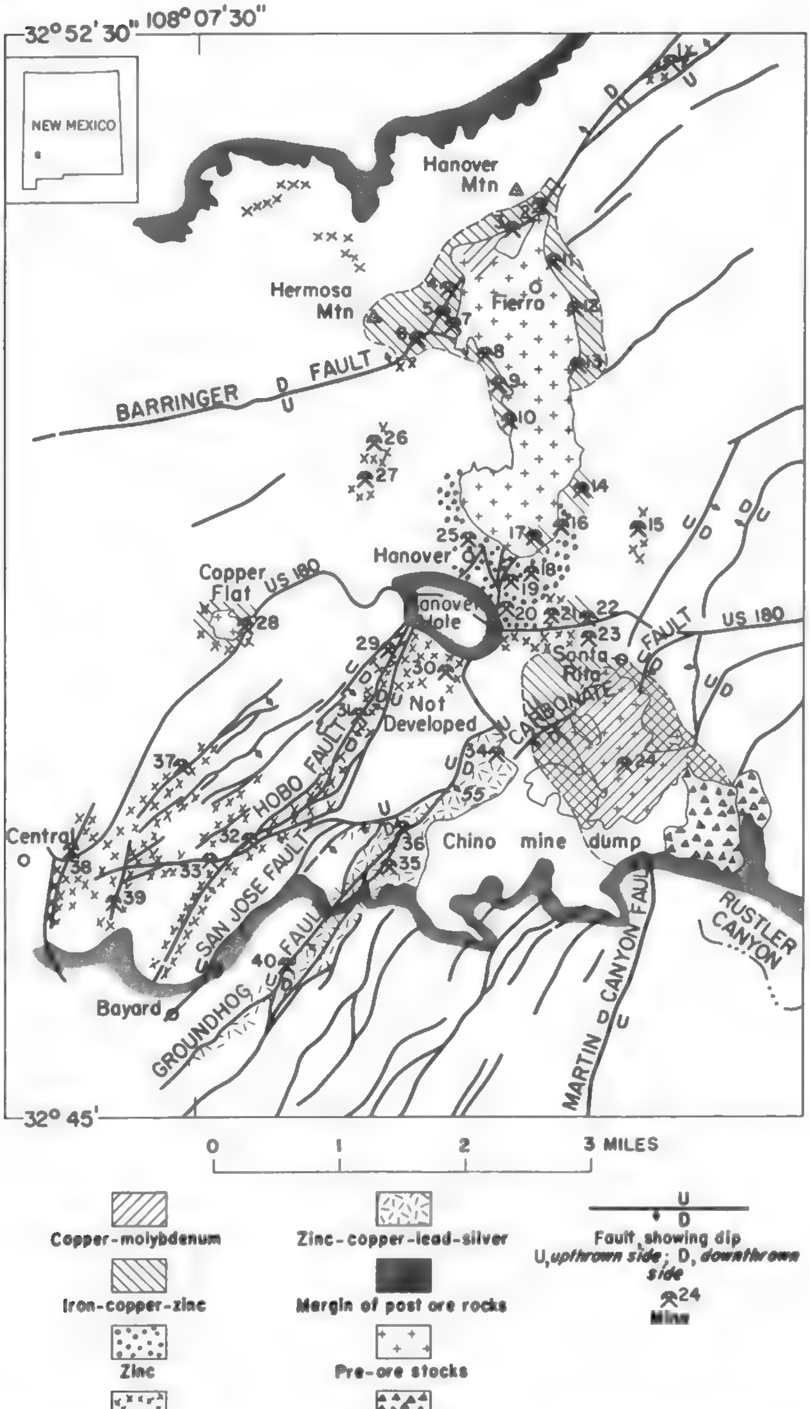


FIGURE 40.—Location of principal mines and types of ore in Central district, Grant County, N. Mex.

List of principal mines in Central district, Grant County, N. Mex., shown on figure 40

1. Shingle Canyon	21. Kearney
2. Emma	22. Nugent
3. Hanover	23. Oswald() No. 2
4. Modoc	24. Chino
5. Continental	25. Empire
6. Pearson	26. North Star
7. Anson S	27. Mountain Home
8. Hanover Bessemer	28. Copper Flat
9. Union Hill	29. Blackhawk
10. Republic Iron	30. Princess
11. Jim Fair	31. Hobo
12. Humboldt	32. Bullfrog
13. Honeycomb	33. Slate
14. El Paso	34. Treasure Vault
15. Grant County	35. Groundhog, Star shaft
16. Pewabic	36. Ivanhoe
17. Philadelphia	37. Three Brothers
18. Thunderbolt	38. Peerless
19. Republic	39. Silver King
20. Oswaldo No. 1	40. Lucky Bill

nel ways for mineralizing solutions. They may occur in igneous, metamorphic, or sedimentary rocks, and they are usually only a few feet wide but may have a considerable horizontal and vertical extent. Deposits consisting of ore minerals that largely or completely replace a mass of rock are called replacement deposits. They usually occur in limestone, commonly along a fracture or a. geologic contact that served as a feeding channel for the mineralizing solutions; they are of irregular shape and differ in size. Because most veins and replacement deposits are smaller and must be mined by more costly underground methods, the ore, to be minable, has to be higher grade than in the disseminated type of deposit. Deposits of the disseminated type have been most productive in New Mexico but veins and replacement deposits have yielded important amounts of copper in some districts and all three types have been productive in the Central district, Grant County (fig. 40) .

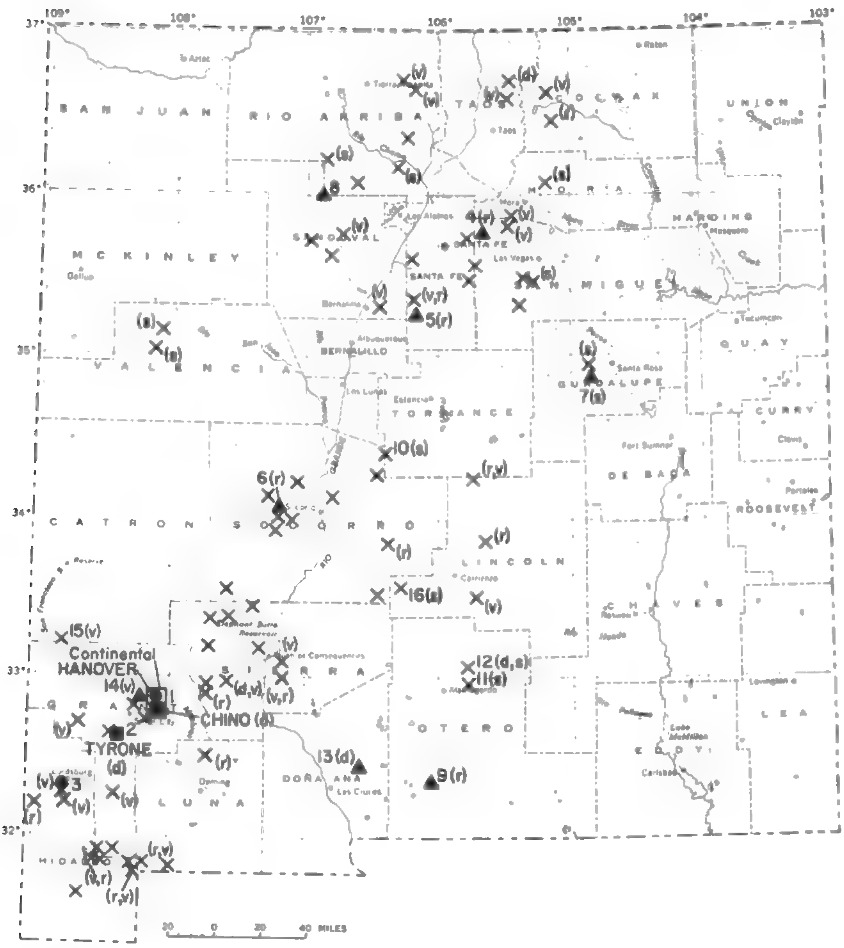
A fourth geologic type of copper deposit, commonly called the "red beds" type, is widely distributed in New Mexico but has not been very productive because most bodies are small. The deposits occur in lenses of coarse-grained arkosic sandstone; the ore minerals partly fill the sandstone pores and partly replace the sand grains, the cementing material and, also, fragments of fossil wood in the sandstone. The origin of these deposits and the source of their copper are not definitely known.

There are many copper minerals, but the copper sulfides chalcocite ($Cu2S$) and chalcopyrite ($CuFeS_2$) are the principal ore minerals. The copper carbonates, malachite and azurite, are ore minerals in the oxidized zones of some deposits, and they are conspicuous at the outcrop of many copper deposits because they are bright green and blue. Native copper is also an ore mineral in the oxidized zones of some deposits.

Varying amounts of other metals, especially gold, silver, lead, zinc, iron, and molybdenum occur in many copper deposits and they are recovered as coproducts or byproducts from some copper deposits in New Mexico. Conversely, some copper is recovered as a byproduct from certain lead and zinc deposits in the State.

HISTORY AND PRODUCTION

The first significant copper mining venture in the New Mexico area began about 1804 at Santa Rita, Grant County. Mines in this district have been operated by various individuals and companies nearly every year since then. Mining began at the Hanover mine (No. 3, fig. 41) near Fierro, Grant County, in 1858 (Raymond, 1870). Shortly after the Civil War, numerous prospectors came to the New Mexico Territory and began intensive searches for metal deposits. Prospecting reached its peak about 1880 and, by 1882, nearly every mining district in the State today, about 140 in all, had been discovered. Copper has been produced from 61 of these mining districts and it is the metal of principal yield from 38 districts. The oxidized and enriched ores at and near the surface in most of these districts were soon exhausted and mining activity declined rapidly when the lower grade, unoxidized sulfide ores were encountered and when the price of silver decreased in the 1890's. Mining was resumed in many of these districts, however, in later years when milling equipment and techniques were devised to treat complex sulfide ores.



EXPLANATION

Copper-producing districts or mines, showing relative amount of production plus estimated potential in tons

More than 1,000,000	10 - 1,000
50,000 - 1,000,000	
1,000 - 50,000	Area of Central mining district

Types of deposits

(d) Disseminated (porphyry)
(v) Vein
(r) Replacement
(s) Disseminated in "Red Beds"

FIGURE 41.—Copper in New Mexico. (Districts identified by number are described in table 22.)

In 1963 copper accounted for about 7 percent of the total value of mineral production in the State; it was exceeded in value only by petroleum, natural gas, potassium salts, and uranium ore. Three mines (the Chino and Continental in the Central district, Grant County, and the Bonney-Miser's Chest in the Lordsburg district, Hidalgo County) accounted for 98.7 percent of the total copper production. The remaining 1.3 percent was obtained from 36 different sources in 7 counties. Copper production in New Mexico is summarized in tables 20 and 21.

TABLE 20.—*Copper production in New Mexico from 1804 through 1963*

Interval	Short tons	Value
1804–79 [1]	15, 000	$6, 000, 000
1880–1903 [1]	28, 683	7, 217, 170
1904–30 [1]	672, 579	234, 420, 138
1931–54 [1]	1, 191, 179	413, 616, 359
1954–63 [2]	616, 076	399, 986, 965
Total, 1804–1963	2, 519, 517	1, 061, 240, 632

[1] Figures for 1804–1954 are from table 21, Bulletin 39, Resources of New Mexico, by E. C. Anderson, 1957, New Mexico Bureau of Mines.
[2] From Minerals Yearbooks, U.S. Bureau of Mines.

TABLE 21.—*Copper production in New Mexico by counties from 1804 through 1963* [1]

Rank	County	Short tons
1	Grant	2, 363, 652
2	Hidalgo	77, 845
3	San Miguel	9, 300
4	Santa Fe	7, 612
5	Guadalupe	6, 407
6	Socorro	5, 775
7	Otero	3, 315
8	Dona Ana	1, 378
9	Catron	485
10	Sierra	464
11	Lincoln	223
12	Colfax	112
13	Luna	47

[1] Figures from U.S. Bureau of Mines, 1953–63, compiled by Ruth Willson.

The principal copper-producing districts in New Mexico are shown in figure 41. Four size categories are shown: deposits that contain 10 to 1,000 tons, 1,000 to 50,000 tons, 50,000 to 1 million tons, and over 1 million tons of recoverable copper. Four morphologic types of deposits have been distinguished on the map by letter symbols: (d) disseminated (porphyry), (r) replacement, (v) vein, (s) "red beds" type in sandstone. The symbols show the location of either individual mines or the approximate centers of districts. The districts having a recorded production of over 200 tons of copper are numbered and briefly described in table 22. Larger deposits representative of each of the four geologic types of deposits are described in the following text.

TABLE 22.—*Principal copper districts in New Mexico*

Map No.	County and district and approximate total copper production through 1963 (in short tons)	Geologic types of deposits	Principal references (see also Anderson, 1957, relative to all localities)
1	Grant County, Central district; 2,300,000 tons.	Disseminated deposits in igneous and sedimentary rocks, replacement deposits with lead and zinc sulfides or magnetite in limestone, and veins with lead and zinc sulfides along faults in igneous and sedimentary rocks.	Spencer and Paige, 1935; Lasky, 1936; Schmitt, 1939; Kerr and others, 1950; Leroy, 1954; Hernon and others, 1953; Jones and others, 1961; Parsons, 1957.
2	Grant County, Tyrone or Burro Mountain district; more than 25,000 tons.	Veins and disseminated deposits in fractured zones only the higher grade bodies have been mined, but large blocks of ground are mineralized and offer the possibility of exploitation by leaching or large-scale mining methods.	Paige, 1922; Lindgren and others, 1910; Somers, 1916.
3	Hidalgo County, Lordsburg district; more than 60,000 tons.	Veins in igneous rocks; some gold and silver recovered with the copper.	Lasky, 1938; Youtz, 1931; Jones, F. A., 1907; Lindgren and others, 1910.
4	San Miguel County, Willow Creek district; 9,000 tons.	Replacement bodies of zinc, lead, and copper minerals with some gold and silver in a highly sheared zone in igneous rock.	Harley, G. T., 1940.
5	Santa Fe County, New Placers district; 7,500 tons.	Replacement bodies of zinc and lead sulfides with gold and silver in limestone near intrusive contacts with igneous rock.	Lindgren and others, 1910; Smith and others, 1945.
6	Socorro County, Magdalena district; 5,500 tons.	Replacement bodies of zinc and lead sulfides with subordinate copper sulfides and some silver and a little gold in limestone near intrusive contacts with igneous rock.	Loughlin and Koschmann, 1942; Lindgren and others, 1910.
7	Guadalupe County, Pastura or Pintado district; 5,000 tons.	"Red beds" type, consisting of oxidized copper minerals that impregnate sandstone and form tabular bodies nearly concordant with bedding.	Harley, G. T., 1940.
8	Sandoval County, Nacimiento district; 3,150 tons.	"Red beds" type, consisting of chalcocite and oxidized copper minerals that partly impregnate sandstone replace fossil wood, forming small scattered bodies.	Lindgren and others, 1910; Fischer, 1937, p. 90; Gott and Erickson, 1952.
9	Otero County, Orogrande district; 3,300 tons.	Replacement bodies of chalcopyrite with a little lead, gold, and silver in limestone near intrusive contacts with igneous rock.	Lindgren and others, 1910.
10	Torrance County, Scholle district; 500 tons.	"Red beds" type consisting of chalcocite and oxidized copper minerals impregnating sandstone and replacing fossil wood, forming small scattered bodies.	Fischer, 1937.
11	Otero County, Sacramento district; small tonnage.	"Red beds" type, consisting of bodies of copper sulfides and similar bodies of lead sulfide that impregnate arkosic sandstone.	
12	Otero County, Tularosa or Bent district; small tonnage.	Veins of copper sulfides in a mass of intrusive igneous rock and adjacent sedimentary rocks, with some disseminated copper minerals in these rocks.	Lindgren and others, 1910.
13	Dona Ana County, Organ district; 2,000 tons.	Veins along faults and replacement deposits in limestone consist of sulfides of copper, zinc, and lead with some silver.	Dunham, 1935; Soule, 1951.
14	Grant County, Pinos Altos district; 1,178 tons.	Veins in intrusive igneous rocks and replacement bodies in adjacent limestone consist of sulfides of zinc, lead, and copper with some gold and silver.	Paige, 1911.
15	Catron County, Mogollon district; 500 tons.	Veins valuable mainly for gold and silver but containing sulfides of copper and lead in volcanic rocks.	Ferguson, 1927; Lindgren and others, 1910.
16	Lincoln County, Oscura or Estey district; 222 tons.	"Red beds" type, consisting of oxidized copper minerals and a little chalcocite that partly impregnate sandstone and replace plant fossils.	Griswold, 1959, p. 105.

DISSEMINATED DEPOSITS

Two major disseminated copper deposits occur in Grant County, the Chino mine in the Central district, and the Burro Mountains Mine in the Tyrone district (Paige, 1922). The Chino mine is ranked fifth among producing copper mines in the United States, and each year yields 55,000 to 70,000 tons of copper. Evidence of the extent and intensity of primary metallization in the Santa Rita stock and adjoining wall rock, which took place about 60 million years ago, is masked by the effects of two periods of leaching and enrichment by percolation of meteoric water. The top of the zone enriched with secondary chalcocite is a highly irregular surface, and is clearly marked by the color change in the walls of the pit. The depth to the top of the ore zone rs variable, ranging from a few tens to as much as 600 feet (Ballmer, 1949, p. 27). The base of the enriched zone is evidently as irregular as the top, for the thickness of the enriched zone ranges from less than 300 to a maximum of about 700 feet. The multi-million-ton bodies of disseminated chalocite ore within the pit area are irregular in plan and section and are separated by even larger bodies of low-grade rock. By blending low- and high-grade ore, a greater tonnage of ore of nearly constant assay value can be sent to the mill. Blocks of ground containing less than the cutoff grade of copper are mined and the rock is trucked to nearby leach or waste dumps. Molybdenite is only sporadically distributed in parts of the ore body, but still, Chino ranks high among the world's producers of molybdenum (Parsons, 1957, p. 130). Native copper is abundant locally, especially in the Beartooth Quartzite close to the surface.

Chalcocite has been noted to a depth of 1,000 feet and native copper and oxidized copper have been intersected at a depth of 1,200 feet in prospect drill holes (Ballmer, 1953, p. 131). Disseminated ore, which has been the principal type mined to date, is found in altered igneous rocks and in altered shales and sandstones of Late Cretaceous age (Spencer and Paige, 1935, Kerr and others, 1950, Leroy, 1954). Replacement bodies of magnetite and chalcopyrite, on the other hand, occur in the limestones adjacent and subjacent to the bodies of disseminated ore. Mining of relatively shallow bodies of this type began a few years ago, and will become increasingly important. In 1962, 38.9 percent of the 73,683 tons of copper produced from the Chino mine was precipitated from waters circulating through the leach dumps (Annual Report of Kennecott Copper Corp., 1962). For many years almost one-fourth of the total production at Chino has come from the precipitating plant (Parsons, 1957, p. 127). For decades after the minable ore has been depleted, thousands of tons of precipitate copper will undoubtedly be produced annually by leaching the dumps and the mine area.

The principal copper deposits of the Tyrone district are chalcocite ore bodies in quartz monzonite porphyry and granite and they have all the characteristics of typical disseminated copper deposits. Only secondarily enriched bodies have proved minable in the past. Chalcocite is either disseminated regularly throughout large masses of sheared and fractured country rock or is concentrated along exceptionally strong veins or shear zones. Valuable ore bodies of both types have been found (Paige, 1922). The principal ore bodies lie within a

northeastward-trending zone of fracture. Within this zone, two major groups of ore bodies, lying about three-quarters of a mile apart, had been delineated by 1922 (Paige, 1922) . The relatively high-grade ore bodies are said to range in size from half a million to several million tons. One of the two major groups is in the vicinity of Leopold and includes the East ore body, which is 700 feet long and a maximum of 600 feet in width. The other major group of deposits, in the vicinity of Tyrone, includes numerous distinct major veins as well as blocks of ore. The Leopold group of deposits is in Precambrian granite whereas the Tyrone group is in a quartz monzonite stock of Late Cretaceous or early Tertiary age. In addition to these two groups there are numerous veins and minor deposits within, and outside of the main fracture zone. The country rock has been leached of its copper locally to depths of 700 feet or more, and the irregular zone enriched in copper that underlies the oxidized and leached zone has a maximum thickness of about 300 feet (Anderson, 1957, p. 48) . The margins of the ore bodies are indefinite, being determined by the copper content, the price of copper, mining and milling costs, and other economic factors. In 1915, rock containing 2 percent copper was considered ore. A considerable tonnage of ore had been blocked out averaging 3.16 percent and at a lower cutoff more than twice as much ore—averaging 2.31 percent—was outlined. These two amounts together averaged 2.58 percent (Paige, 1922, p. 50). At a still lower cutoff yielding an average minimum grade of 1.75 percent copper, the tonnage of ore was again doubled. Between 1950 and 1958 the principal owner in the district, Phelps Dodge Corp., did extensive drilling and the results are said to be encouraging (Annual Report of Phelps Dodge Corp., 1958) .

Other examples of disseminated copper deposits of potential economic value in New Mexico are the Copper Flat area in the Hillsboro district, Sierra County ; the Torpedo mine in the Organ district, Dona Ana County ; and the Virginia mine in the Tularosa (Bent) district in Otero County. At Copper Flat (Harley, 1934; Kuellmer, 1955) chalcopyrite, pyrite, molybdenite, chalcocite, and copper oxides with some gold and a little silver, are disseminated in a factured quartz monzonite stock, and also occur in quartz veins throughout the area. According to Kuellmer (1955, p. 37) a few hundred samples from the central part of the stock average 0.35 percent copper, and he suggests that this material might be minable at some future date. The Copper Flat deposit appears to be typical of many disseminated porphyries prior to enrichment by supergene processes and a careful study of it might reveal information concerning the genesis of such copper deposits. Dunham (1935, p. 215) states that the occurrence and nature of the primary ore at the Torpedo mine in the Organ district, consisting of quartz, pyrite, and chalcopyrite, closely resembles that of the disseminated (porphyry) copper type. At the time of his examination, there remained a body of enriched ore of unknown extent and probably a large body of low-grade ore, all of which "might well some day offer possibilities for an operation of moderate scale" (Dunham, 1935, p. 219). However, exploration in 1946-47 by E. S. Longyear Co. and New Jersey Zinc Exploration Co., and in 1949-50 by the U.S. Bureau of Mines (Smile, 1951) was not encouraging. The ore in the Tularosa (Bent) district (Lindgren and others, 1910; Fischer, 1937) consists of veins of chalcocite with some chalcopyrite, bornite, and pyrite along

joints and faults in diorite porphyry. Dolomite, barite, and a hydrocarbon are common in the veins, and in this respect they differ from veins in disseminated porphyry deposits.

REPLACEMENT DEPOSITS

Replacement deposits in carbonate and silicate rocks have yielded important amounts of copper, even though copper is commonly a byproduct or at best a coproduct of zinc, lead, or iron in such deposits. In parts of the Central district areas containing zinc and zinc-lead-silver replacement ore bodies (fig. 40) in carbonate rocks also contain pods and streaks of chalcopyrite-rich ore. Examples of this association in the Central district are found in the Ground Hog mine (Lasky, 1936), Combination mine (Schmitt, 1933), and in the Oswaldo Princess Pewabic (Schmitt, 1939), and Hobo mines. (For details see preceding chapters on silver, lead, and zinc ores.) In other parts of the district massive bodies of iron-copper-zinc ore occur in dolomites and limestones of Paleozoic age. Examples of such deposits are in the Continental, Anson S., Modoc, Hanover, Emma, Republic, Union, Philadelphia, and Chino mines. These iron-copper-zinc deposits are located along the main channelways followed by the ascending fluids; that is, along the margins of the discordant intrusive bodies, stocks and dikes, and along major faults that intersect those margins (fig. 40) . These deposits were the earliest to form in the district (Jones and others, 1961). Between 1916 and 1932, 2,319,981 long tons of ore assaying 54.43 percent iron and 0.504 percent copper were mined from the Union Hill, Republic, Anson S., and Continental. Kelley (1949) reports that the total production of this type of ore is 5,060,964 long tons, averaging about 0.37 percent copper.

In places unoxidized ore contains about 0.6 percent copper (Kniffin, L. M., 1930) , and in deposits close to the Barringer fault and northwest of the Chino pit, the copper content averages between 1 and 2 percent. Pyrite, chalcopyrite, and pyrrhotite are the principal sulfides in the magnetite ore; sphalerite and molybdenite occur locally. In 1963 preparations were underway for large-scale mining of this type of ore in two sectors of the Central mining district, at Santa Rita and Fierro. Several hundred tons of magnetite-chalcopyrite-sphalerite ore have been produced daily for the past several years from the Continental mine which, in 1962, ranked third in copper production in the State. The ore is currently being mined from the Abo and Syrena Formations which crop out along the west side of the granodiorite stock, north of the Barringer fault. The intensively altered beds dip gently westward, beneath Hermosa Mountain. A pronounced magnetic anomaly centered at Hermosa Mountain has been inferred to overlie a large deposit of magnetite, which may contain significant amounts of copper and zinc (Jones and others, 1964).

Other replacement deposits of carbonate rocks in which copper is associated with zinc and lead are found in the San Pedro mine, New Placers district, Santa Fe County (Smith and others, 1945, Anderson, 1957) • in the Magdalena district, Socorro County (Loughlin and Koschmann, 1942) ' • in the Orogrande district, Otero County (Anderson, 1957) ; in the Cleveland mine, West Pinos Altos district, Grant County; and, to a lesser extent, in all the minor zinc-lead-silver replace-

ment deposits in New Mexico. Brief descriptions of the principal ores of this type are given in table 22 and further details may be found in the preceding chapters. The occurrence of mixed sulfide ore as a replacement of schistose diabase in the Pecos mine, Willow Creek district, San Miguel County is unique in the State (Harley, 1940). The tenor of the ore, however, is fairly typical of the large replacement bodies in carbonate rocks, such as those of the Ground Hog mine, in the Central district (Lasky and Hoagland, 1948; Lasky, 1936). The total production of copper from base-metal replacement deposits in New Mexico in the past century might equal only a few months' production from the Chino mine. The replacement deposits of magnetite-chalcopyrite, on the other hand, are expected to account for a substantial part of the copper produced in New Mexico during the next decade.

VEIN DEPOSITS

The only vein deposits in New Mexico that have yielded a substantial tonnage of copper are in the Lordsburg and the Central districts. In 1963, as in all years since 1936, the Banner Mining Co. was the principal copper producer in the Lordsburg district and copper constituted about 87 percent of the total value of metals produced in Hidalgo County. The annual report of the company for 1962 reveals that 95,270 tons of ore were produced. The metal content of the 7,864 tons of concentrate produced from ores milled in 1962 was 1,208 ounces of gold, 55,952 ounces of silver, and 2,142.5 tons of copper (U.S. Bureau of Mines, Minerals Yearbook, 1962, p. 746, vol. III). Extensive exploration and development work was continuing in 1963. The deposits in the northern part of the district belong to the copper-tourmaline type, and the Emerald vein, which had been mined continuously for a strike length of 4,350 feet and a vertical depth of 1,900 feet, and which produced about 1,500,000 tons of ore before being closed in 1931, contained the most productive deposit of this type in the United States. The average ore in this deposit contained 2.8 percent copper, as well as 1.23 ounces of silver and 0.11 ounces of gold, per ton, and this grade was remarkably constant throughout the deposit. The principal mine on the Emerald vein, the Eighty-Five mine, owned by Phelps Dodge Corp., was inactive from 1932 until recently when Brannon and Fuller produced some lead- and copper-bearing gold-silver ore.

Production since 1933 has come largely from the Bonney and Miser's Chest mines in the southern part of the district. The veins, which are in basalt rather than granodiorite, although a granodiorite dike cuts erratically across the vein in some workings, consist of overlapping segments striking northeast and dipping steeply northwest (Lasky, 1938, p. 49). These veins contain gold and silver as well as copper sulfide (chalcopyrite) in a barite and carbonate gangue. The Bonney mine was discovered in 1881 and is reported to have produced about 3,380 tons of copper, 300 ounces of silver, and 10,000 ounces of gold to 1931. Other producing mines in the district are the Waldo, Ruth, Anita, Eighty-Five, and Atwood (Anderson, 1957) .

Vein deposits of zinc, lead, and copper were worked prior to 1953 in the southwestern sector of the Central district (fig. 40). The veins are in normal faults, commonly following closely the sheared walls of granodiorite dikes (Duriez and Newman, 1948). The country rocks are quartz diorite sills and beds of sandstone and shale of the Colorado

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Formation. The deposits form lenslike shoots as much as 1,000 feet long, 400 feet downdip, and 25 feet thick in brecciated sill rock, and consist of massive varitextured argentiferous mixtures of sphalerite, chalcopyrite, galena, and pyrite, named in order of abundance, accompanied by quartz and calcite (Lasky, 1936). The average ore in the Ground Hog vein contained about 14 percent zinc, 10 percent lead, 5 percent copper, as well as 10 ounces of silver per ton (Lasky and Hoagland, 1948). In places, replacement deposits in carbonate rocks occur below the vein deposits.

Vein deposits of argentiferous zinc-lead along the Hobo, Owl (Bullfrog), and Slate faults farther to the west contain less than 1 percent copper. Similar veins occur in the northwestern sector of the Central district, north of Hermosa Mountain (see fig. 40).

Narrow vein deposits in the Pinos Altos district contain quartz, pyrite, chalcopyrite, calcite, gold, silver, and usually sphalerite, galena, barite and rhodochrosite (Paige, 1911). Symmetrical bending parallel to the vein walls is typical. The sequence from walls to center is : quartz and pyrite; sphalerite and chalcopyrite; quartz and chalcopyrite; sphalerite; quartz with sparse chalcopyrite. The maximum strike length of ore shoots is about 1,500 feet and, although the ore shoots swell locally to widths of 5 feet, the average widths in the district are about 18 inches. Very little production has been recorded since 1932. The U.S. Smelting, Refining & Mining Co. did extensive exploration work in the past decade, exploring for replacement ore in the deeper-seated carbonate rocks below the veins in the andesite breccia, mafic dike rocks, and quartz monzonite.

Numerous other veins of little economic significance in the past, with respect to copper, are known in New Mexico. Copper-bearing veins exist in the Mogollon district, Catron County (Ferguson 1927), associated with silver and gold; Steeple Rock district, Grant County, in zinc, lead, gold-silver veins; White Signal district, Grant County, in gold veins; Sylvanite camp, Hachita district, Hidalgo County (Lasky, 1947), in gold-bismuth veins; Elizabethtown district, Colfax County, in narrow auriferous pyrite veins; Hillsboro district, Sierra County, in quartz-calcite-fluorite-pyrite veins which contains gold and silver; Taos Range, associated with molybdenum and with zinc, lead, silver, and gold (Schilling, 1960, p. 23) ; Chloride district, Sierra County, along with gold and silver (Harley, 1934) ; and in many other districts within the State.

"RED BEDS" COPPER DEPOSITS

Copper deposits in sandstone, shale, and conglomerate of Permian and Triassic age are numerous and widespread in central New Mexico (fig. 41). Typically the deposits are lenticular or tabular and nearly parallel to the bedding. The ore minerals, chiefly sulfides, oxides, and carbonates of cooper, mainly fill pores in sedimentary rock. Chalcocite is the most common primary mineral and occurs as disseminations of irregular replacement masses in sandstone, as nodules in shale, and as pseudomorphs after fosil wood and pyrite grains. Small amounts of native copper, cuprite, chalcopyrite, covellite, bornite, sphalerite, pyrite and galena are present in places. Malachite is the most conspicuous mineral and is more abundant than azurite or chrysocolla. Trace to small amounts of silver, lead, nickel, cobalt, chromium, molybdenum, uranium, vanadium and zinc are present in some deposits.

Gott and Erickson (1952) called attention to the common occurrence of asphaltite or other hydrocarbons in this type of deposit.

Many of the deposits of this class are small; according to Anderson (1957) the Stauber mine, Pastura (Pintada) district (locality 7, fig. 41) in Guadalupe County, is the only deposit that has yielded an important amount of ore. The ore is confined to one bed in the Santa Rosa Sandstone (Triassic age) (Harley, 1940, p. 91) and consists largely of oxides and carbonates of copper. From 1925 through 1930, the mine yielded 2,618 tons of copper from 54,661 tons of ore having an average grade of 4.78 percent copper. The mine was closed from 1931 through 1939, but operated during World War II. It has produced sporadically since then when siliceous fluxing ore is in demand at the El Paso smelter.

Considerable production came from two areas on the west flank of the Sierra Nacimiento uplift (Cuba, Abiquiu and Gallina districts, (locality 8) (Gott and Erickson, 1952, Fischer, 1937). The deposits are in the Poleo Sandstone Lentil of the Chinle Formation of Triassic age. Malachite, chalcocite, azurite, and chrysocolla occur in fractures, are disseminated through sandstone, and replace carbonized wood.

The copper deposits of the Coyote district, Mora County (Zeller and Baltz, 1954) are confined to the lower 2,000 feet of the Sangre de Cristo Formation of Pennsylvanian and Permian age. The deposits occur in a narrow belt extending for 7 miles along Coyote Creek south of Guadalupita, N. Mex. The better deposits average about 2 percent copper but small concentrations may run as high as 6 percent. The average copper ore body assays about 1.5 percent copper and contains less than 1,000 tons of ore (Tschanz and others, 1958). The richest deposits occur in black carbonaceous shale lenses and in adjacent gray shale or arkosic pebble conglomerate. Uranium and vanadium minerals are associated with some of these deposits. The enclosing rock is colored red by iron oxides.

The copper deposits in the Zuni Mountain district, Valencia County, are in the basal beds of the Abo Formation which there rests directly on Precambrian rocks. In the Sacramento district, Otero County, copper-lead mineralization is virtually continuous for a distance of 6 miles between Alamogordo and Cloudcroft (locality 11, fig. 41). About 1.6 million pounds of lead and 100,000 pounds of copper were produced before 1932 (Lasky and Wooton, 1933). Copper is present in another long belt in the Estey district in Lincoln County. Here the eastward dipping Abo Formation crops out three times, being repeated by faulting (Fischer, 1937). Copper is widely disseminated in the Tecolote district southwest of Las Vegas in north-central New Mexico where chalcocite, bornite, chalcopyrite, malachite, and azurite are reported to replace the carbonate cement of arkosic sandstone and, to a lesser extent, kaolinized feldspar. The copper deposits in the Scholle district, Torrance and Socorro Counties (locality 10) are also in the Abo Formation. The ore mineral and habit is typical of the "red beds" type. Silver is present in more than usual amounts.

COPPER RESOURCES

Although few mine reserve data are available for copper, a rough estimate is possible on the basis of past production and geologic inference. It is estimated that known, partly developed, and possible re-

serves, to say nothing of undiscovered yet statistically likely resources, of copper in New Mexico are about three times what has been produced to date (2.5 million tons). Most of the reserves for the next decade or two are in Grant County, in disseminated deposits of the Tyrone and the Central districts, and in replacement deposits in carbonate rocks peripheral to three granodiorite stocks in the Central district. The disseminated deposit of the Tyrone district, judging solely from Paige's description (Paige, 1922), ranks among the medium-size deposits, together with Chino, N. Mex., or Ely, Nev., being somewhat smaller than those at Bingham, Utah, or San Manuel, Ariz.

Resources in the Central district are in the extensions of the enriched disseminated chalcocite ores currently being mined, in the bodies of protore of chalcopyrite and molybdenum which presumably exist in the block between the north and south pits and at depth, and in the magnetite-chalcopyrite replacement bodies of limestone and dolomite surrounding the Santa Rita and other stocks. The layers of carbonate rocks aggregate about 2,200 feet, and the upper 1,250 feet of the stratigraphic section, above the Percha Shale, have been the favorable host rocks of zinc, copper, lead ores, as well as magnetite-chalcopyrite ores throughout the district. Northwest and north of the rim of the Chino Pit, in the footwall block of the Carbonate fault, magnetite-chalcopyrite ore is exposed at the surface or lies just beneath the Beartooth Quartzite. Judging entirely from what can be seen at the surface and from the size of the magnetic anomaly (Jones and others, 1964), a large tonnage may be inferred in this sector of the contact zone alone. Similar ore is exposed on the downthrown side of the Carbonate fault and in the northwest and northeast corners of the south pit while the magnetic anomalies indicate that the northeastern margin may be a favorable sector for exploration. The strata along the southwestern margin of the Santa Rita stock, which is elongate along a northwest-southeast axis (Ordonez and others, 1955; Hernon and others, 1964), are a few hundred feet deeper, but contain the full complement of carbonate rocks of Paleozoic age. The block of ground bounded on the west by the Ground Hog-Ivanhoe fault zone, which dips moderately to the east southeast, on the north by the Santa Rita stock, and on the east by the Martin Canyon fault must be considered as one of the most favorable blocks for exploration for replacement bodies of zinc-copper-lead ores in carbonate and brecciated sill rocks (see fig. 40). Also, the southeastward limit of copper mineralization has not been determined. One of the strongest trends of copper ore at Chino extends southeastward through the south pit, in line with Rustler Canyon. Other resources, undoubtedly higher in zinc and lead than copper, probably exist in the mile-long, half-mile-wide block between the Princess mine on the north and the Ground Hog-Ivanhoe mine on the south. The intense alteration (epidote group assemblage) in the preore granodiorite dikes that traverse the middle of this block is favorable. Still other important resources are in the hanging wall (downthrown block) of the Barringer fault, from the Pearson mine on the southwest to the Emma mine on the northeast, a distance of about 1$1/_2$ miles. This ore is largely copper-zinc-lead associated with magnetite and silicated carbonate rocks, but a small amount of disseminated copper ore may exist also. The favorable ground is fairly well outlined by a conspicuous magnetic anomaly (Jones and others, 1964). Brady (1964) reported the discovery of a large ore body in this

block, where preliminary drilling showed "more than 8 million tons of 2.15 percent copper ore equivalent to 172,000 tons of copper. Another 8 million tons of ore are indicated from initial drill data." Two shafts are being sunk about to the base of the Lake Valley Formation at 1,400 to 1,500 feet. The mill will have a capacity of 2,000 to 4,000 tons per day, depending on the availability of water. Production is scheduled to begin in January 1967.

Similar but much smaller resources are in the margin of the small stock at Copper Flat in the west-central part of the Santa Rita quadrangle (Mullen and Storms, 1948; Bacon and Joesting, 1945).

Although no reserve figures are available for the vein deposits in the Lordsburg district, the persistence of the ores with depth and along strike indicates that the numerous veins will continue the present rate of output for the next decade, and will likely produce as much as has been produced to date. In 1932 the known reserves in the Lordsburg district amounted to 150,000 tons of ore said to average 2.8 percent (Lasky, 1938, p. 2, 43) . This would yield at best 4,200 tons of copper, or 21 days production from Chino, operating at present capacity.

The "red beds" copper deposits have not produced significant tonnages in the past, in spite of a favorable price for many years and near surface occurrence. Geologists familiar with this type of deposit hold little hope for significant production in the future.

The increasing importance of precipitate copper derived from leaching operations at disseminated copper deposits, such as at Chino, is noteworthy. In the United States in 1962, 109,200 tons of copper, 9 percent of the total recoverable copper produced, was precipitate copper. Any analysis of resources must include production from the leach dump and mine workings for decades after mining is no longer feasible.

SUGGESTIONS FOR PROSPECTING

On the basis of past production, the southwestern corner of New Mexico, in the counties of Grant, Hidalgo, Luna, Dona Ana, and Sierra, clearly is the most likely area to contain other major copper deposits. This region lies along the eastern extremity of the Arizona copper province, which annually accounts for more than 50 percent of the copper mined in the United States. The most likely areas, concealed beneath pediments, should be prospected by geophysical and geochemical methods utilizing the gravimetric, magnetic, electric, seismic, and thermic properties of rocks and minerals. The projection of mineralized trends in the exposed areas of the mountains and pediments beneath young gravel or volcanic deposits should be given priority. In the prevailing climate the granitic host rocks of the disseminated copper deposits are generally less resistant to erosion than the carbonate rocks that contain the replacement deposits, thus low ground adjacent to all such replacement deposits should be systematically prospected, utilizing modern techniques.

J. R. Cooper pointed out (1956, written communication) that the major metal districts in southwestern New Mexico fall along a northeast trending line (fig. 41) ; two major copper districts, Bisbee, Ariz., and Cananea, Mexico, plus two minor districts, are points on the southwestern projection of this lineament. Although this distribution may be fortuitous, deep-seated flaws in the crust do exist over long distances in many parts of the world, and it is along such

flaws that magmas and fluids are most likely to ascend. This belt deserves careful exploration.

Large, geologically young, northwest trending, basin- and range-type normal faults cross this alinement essentially at right angles and their possible effect on the localization of ore deposits must be considered in assessing the geologic possibilities of any particular area.

Schilling (1960, p. 112-113) states that "the copper-bearing shear zone extending east from the Frazier mine in the Rio Hondo mining district, and the copper-rich shear zone extending west from the Copper King mine in the Red River mining subdistict are favorable for prospecting." He also suggests that disseminated deposits of copper may occur along the Red River in Taos County. Certainly more attention should be focused on the possibility of locating massive replacement deposits in Precambrian metamorphic rocks, beneath the cover of Paleozoic and younger rocks. After all, the discovery of the Pecos mine, one of the most important mines in the State during its life (table 22), was made possible by an accident of erosion. Anderson states (1957, p. 113), "The Sangre de Cristo Mountains surely hold other deposits similar to those of the Pecos mine."

IRON

(By C. M. Harrer, U.S. Bureau of Mines, Denver, Colo.)

Iron, with its many uses, is one of the foundations of the Nation's economy. Enormous amounts of natural iron ore, coal, water, air, and power together with lesser amounts of limestone, other fluxes, and alloying materials are consumed annually in its production. During 1962, over 102 million long tons of iron ore, including direct-shipping ore and beneficiated material (pellets and sinter), was consumed in U.S. blast and steel furnaces. Of this almost 28 million long tons were imported. In that year, 98.3 million short tons of steel were produced in the United States.

Iron and steel companies employ about three-quarters of a million people in their operations. Their purchases total nearly $6 billion annually and their expenditures contribute to the employment of nearly 23% million people in other industries (American Iron & Steel Institute: "The Competitive Challenge to Steel," 1963 edition).

The earliest use of iron oxides in New Mexico was by Indians as red and yellow ocher in pigments. Iron ore for metallurgical purposes was first mined in the 1880's when it was used extensively as a flux in the smelting of siliceous gold, silver, and copper ores. During 1889-99, about 234,000 tons of iron ore was mined in various parts of the State as flux for nonferrous smelters and for use in the blast furnaces of the Colorado Fuel & Iron Corp., Pueblo, Colo. (Kelley, 1949). Lincoln County iron ore mining began in the White Oaks district in 1913 ; in the Tecolote district during 1915 ; and in the Jicarilla district during 1918. Otero County iron ore production began in the Orogrande district in 1913.

Iron ore production in New Mexico has been small. Peak prodvetion of 214,t47 tons, during 1927, was only 0.3 percent of national output and 20 percent of the Western States total. As late as 1942 the

New Mexico output, exclusive of manganiferous iron ore, was 6 percent of the total for the Western States. Production through 1962 totaled 8.2 million tons, utilized mainly by the Colorado Fuel & Iron Corp. smelter at Pueblo, Colo. This production was comprised of 5.5 million tons of high-grade magnetite from the Hanover-Fierro district, Grant County, plus minor amounts from Otero, Lincoln, and Socorro Counties, and 2.7 million tons of manganiferous iron ore from the Silver City district of Grant County. The latter ore was mainly earthy hematite and pyrolusite together with some magnetite, specularite, and limonite and contained as much as 12 percent manganese and 30 to 40 percent iron. Since 1931, production of magnetite iron ore in New Mexico has been very small and was mainly for use as heavy aggregate in cement manufacture and for coating underwater pipelines. The value of all iron ores produced through 1962 is estimated at $17.3 million.

New Mexico has no iron- and steel-smelting facilities and its potential iron ores would have to be consumed by the Western States iron and steel industry, which is concentrated in California, Colorado, Texas, and Utah. At present, most of the ores and agglomerates on which the western iron and steel industry is dependent come mainly from California, Utah, and Wyoming.

Prior to World War II, most iron ore was used directly without beneficiation. Since then, the use of beneficiated iron ore in the form of sinter or pellets has increased enormously. In 1962, only 15 percent of the iron ore mined was used directly in furnaces; the remaining 85 percent was treated in some type of beneficiation plant (Minerals Yearbook, 1962, vol. 1, p. 659). The trend to increased use of beneficiated and agglomerated material is expected to continue.

Most iron ore and agglomerate used in the western iron and steel industry is smelted in blast furnaces to produce pig iron. Further processing yields a multitude of iron and steel products. Because western blast furnaces consume a total of 7 to over 8 million tons of ores and agglomerates annually, and individually about 900,000 tons annually (Minerals Yearbook, 1962, vol. 1, pp. 691-693), it is apparent that small deposits of a few hundred to a few million tons are only a short-lived and temporary supply of raw materials. Such small deposits are important mainly as sources of iron oxides for purposes other than for iron and steel production.

New Mexico iron ore deposits occur in a variety of mineralogic and geologic forms. The most important ore minerals are the oxides magnetite (72 percent iron) and hematite (70 percent iron). Ore minerals of minor importance include the carbonate siderite, ferroan and manganoan carbonates, the sulfides pyrite and pyrrhotite, and the sulfate j arosite.

Many of the New Mexico iron ore deposits are contact pyrometasomatic bodies in Paleozoic calcareous sedimentary rocks, and are associated with Late Cretaceous or early Tertiary intrusive masses. The pyrometasomatic bodies are irregularly tabular and lenticular and at least one, the Capitan in Lincoln County, is annular. The ore bodies include branches extending outward from the main mass. In many, as exemplified by those at Orogrande, Otero County, the ore consists of massive to disseminated magnetite and hematite (some as specularite), in layers parallel to the bedding of the rocks that they have replaced. Other deposits, as for example those at Iron Mountain, Sierra County,

are tactite, or silicated rock bodies, that contain abundant magnetite. Some of the generally small Lincoln County deposits of magnetite-hematite with little or no silicate gangue may possibly be farther from intrusive contacts, and are thus inferred to be lower temperature replacement bodies of hydrothermal origin.

For the most part, the grade of the magnetite-hematite contact pyrometasomatic deposits and lower temperature-hydrothermal bodies ranges from 35 to 60 percent iron. According to Kelley (1949 p. 47), the average grade of ore shipped ranges from 51.4 to 58.2 percent iron, although 1 shipment of 10 cars from the Fierro district averaged 65.5 percent iron. According to Kelley, these figures are not an indication of the general grade of ore, but reflect specifications as to minimum grade set by the consumers, and resulted from small-scale, selective mining and sorting. During large-scale mining of the Fierro-Hanover deposits, average grade dropped to about 55 percent iron.

Extensive oolitic hematite sedimentary beds form part of the Bliss Sandstone of Cambrian and Ordovician age in Sierra and Grant Counties. These deposits are low in grade, ranging generally from 20 to 25 percent iron.

Iron formation (frequently termed "taconite" in the Mesabi Range, Minn.) occurs in metasediments of Precambrian age in Rio Arriba (Bertholf, 1960) and Taos (Schilling, 1960, p. 23) Counties. In Rio Arriba County, the thickness of the iron formation has not been determined with certainty, but a preliminary magnetometer survey and geologic reconnaissance by Bertholf indicate that the thickness may be as much as 700 feet. The grade ranges from about 30 to about 40 percent iron. In Taos County, the beds are up to 50 feet thick and the richer parts contain as much as 25 percent iron. This occurrence has a potential of 100 million tons (table 23).

TABLE 23.—*Major iron districts, deposits, and occurrences in New Mexico*

Locality (fig. 42)	Name and location of deposit	Type of deposit	Estimated total reserves (millions of long tons)	Approximate iron content (percent)	Potentiality	References
1	Orogrande district, Jarilla Mountains, Tps. 21–22 S., R. 8 E., Otero County.	Magnetite and hematite as contact pyrometasomatic replacements in Paleozoic limestone.	0.332	40–55	Larger than estimated if lower grade iron is included.	Kelley (1949, pp. 51 and 223); Harrer and Kelly (1963, pp. 79–84).
2	Robledo Mountains-Iron Hill hematite, T. 22 S., R. 1 W., Dona Ana County.	Hematite, goethite, limonite and ocher replacing shattered zones and cavities in Magdalena Limestone.	.02	50–55	About as estimated	Kelley (1949, p. 50).
3	Boston Hill, secs. 3, 4, 9, 10, T. 18 S., R. 14 W., Grant County.	Manganiferous hematite and magnetite. Supergene enrichment of carbonates.	10	[1] 35–40	Larger than estimated if lower grades are considered.	Kelley (1949, p. 51); Harrer and Kelly (1963, p. 34).
4	Chloride Flat, Tps. 17–18 S., R. 14 W., Grant County.	Manganiferous hematite and limonite. Supergene enrichment of carbonates.	.6	[1] 35–40	Large, including low grade	Do.
5	Sycamore-Bear Canyons, Pinos Altos Mountains district, Tps. 16–17 S., Rs. 13–15 W., Grant County.	Oolitic hematite. Syngenetic in Cambrian Bliss Sandstone. Magnetic anomalies, T. 17 S., R. 13 W.	5	25	About as estimated	Kelley (1949, p. 51 and 223); Harrer and Kelly (1963, pp. 79–84); Jones, Case, and Pratt (1964).
6	Fierro-Hanover district, T. 17 S., R. 12 W., Grant County.	Magnetite and hematite as contact pyrometasomatic replacements in Paleozoic calcareous and dolomitic rocks	50	35–55	Large, including low grade. Magnetic anomalies.	Kelley (1949, p. 50); Harrer and Kelly (1963, pp. 27–30); Jones, Case, and Pratt (1964).
7	Santa Rita, Nugent, and Booth mines, Tps. 17–18 S., R. 12 W., Grant County.	Magnetite and hematite as contact pyrometasomatic replacements in Carboniferous Oswaldo Formation. Magnetic anomalies.	.03	35–50	Much larger than estimated when considering low-grade magnetite in Santa Rita copper pit and replacements in Carboniferous Oswaldo Formation north of Santa Rita.	Kelley (1949, p. 50, 120, 122); Harrer and Kelly (1963, pp. 30, 31); Jones, Case, and Pratt (1964).
8	Copper Flat-Bayard, T. 17 S., R. 12 W., Grant County.	Hematite, magnetite, and limonite as contact metamorphic replacements of Carboniferous Oswaldo Formation.	.05	45–55	About as estimated	Kelley (1949, p. 50).
9	Black-Mimbres Mountains-Pierce Canyon hematite (Latham iron mine), T. 17 S., R. 8 W., Sierra County.	Oolitic hematite. Syngenetic, sedimentary origin, in Cambrian Bliss Sandstone.	.48	20–25	Possibly larger than estimated when considering structure and extensions related to origin.	Kelley (1949, p. 51); Harrer Kelly (1963, pp. 72–73).
10	Caballo Mountains, Tps. 14–17 S., R. 4 W., Sierra County.	Titaniferous oolitic hematite. Syngenetic. sedimentary origin, in Cambrian Bliss Sandstone.	63	25–35	Larger than estimated when considering possible extensions related to origin.	Kelley (1949, p. 51); Harrer and Kelly (1963, pp. 66–72).
11	Cuchillo Mountains and Cuchillo Negro district, T. 11 S., R. 7 W., Sierra County	Discontinuous and lenticular bodies of magnetite as contact pyrometasomatic replacements of Ordovician Limestone.	.040	40–55	About as estimated	Kelley (1949, p. 51).

[1] With 12 percent Mn.

TABLE 23.—*Major iron districts, deposits, and occurrences in New Mexico*—Continued

Locality (fig. 42)	Name and location of deposit	Type of deposit	Estimated total reserves (millions of long tons)	Approximate iron content (percent)	Potentiality	References
12	Iron Mountain-Cuchillo Range magnetite tactite, T. 10 S., R. 8 W., Sierra County.	Magnetite as a pyrometasomatic replacement in Pennsylvanian Magdalena limestone.	10.5	20–40	Large when low grade is included.	Kelley (1949, p. 51); Harrer and Kelly (1963, pp. 74–76).
13	Capitan. Capitan Mountains, T. 8 S., R. 14 E., Lincoln County	Magnetite and hematite as contact pyrometasomatic replacements in Permian limestone of the San Andres Formation.	3.1	45–55	Many more magnetite-hematite outcrops in Capitan Mountains. Potential of district could be large.	Kelley (1949, p. 51); Harrer and Kelly (1963, pp. 37–40).
14	White Oaks-Lone Mountain district, T. 6 S., R. 11 E., Lincoln County.	Hematite and magnetite, partly manganiferous, as contact pyrometasomatic replacements of the Permian San Andres Formation.	.045	45–55	About as estimated.	Kelley (1949, p. 51).
15	Jicarilla Mountains district, Tps. 4, 5, and 6 S., Rs. 12–13 E., Lincoln County.	Magnetite as contact pyrometasomatic replacements of Permian limestones.	.024	45–55	do.	Do.
16	Tecolote Hills district, T. 3 S., R. 12 E., Lincoln County.	Magnetite as contact pyrometasomatic replacements of Permian San Andres and Yeso Formations.	.013	45–55	do.	Do.
17	Gallinas Mountains-Red Cloud district, Tps. 1, 2, and 3 S., Rs. 11, 12, and 15 E., Lincoln County.	Magnetite as contact pyrometasomatic replacements of Paleozoic limestone.	.033	45–55	do.	Do.
18	Jones-Iron Horse-Chupadera Mesa magnetite, Tps. 1, 5, and 6 S., Rs. 6, 7, and 8 E., Socorro and Torrance Counties.	Magnetite and hematite as contact pyrometasomatic replacements of limestones of the Permian Yeso formation.	.683	40–60	Further exploration of magnetites of Chupadera Mesa could prove them large in aggregate.	Kelley (1949, pp. 51 and 223); Harrer and Kelly (1963, pp. 79–84).
19	Santa Fe County-Glorieta Mesa-Kennedy limonite, Ortiz and San Pedro Mountains magnetite.	Supergene ore replacing Permian siltstone and sandstone on Glorieta Mesa. Ortiz and San Pedro Mountains magnetite as contact pyrometasomatic replacements of limestones.	.005	45–55	About as estimated.	Kelley (1949, p. 51).
20	Iron Mountain, unsurveyed, T. 27 N., R. 16 E., Colfax County.	Magnetite as a contact pyrometasomatic replacement of metamorphosed Cretaceous shales.	.04	50–55	About as estimated on the basis of present investigations.	Kelley (1949, p. 50).
21	Cleveland and Burned Gulches and Iron Mountain taconite, Tps. 28–29 N., Rs. 7–8 E., Rio Arriba County.	Magnetite-hematite taconite in Precambrian metasediments.	([2])	29–38	Large, possibly exceeding 100,000,000 tons. Area and deposit requires mapping and exploration of iron formation.	Harrer and Kelly (1963, pp. 60–62); Bertholf (1960, p. 23).

[2] No meaningful estimate possible without exploration; however, potential is considered large.

In some areas, iron has been concentrated by supergene processes, including weathering and the action of surface and subsurface water, resulting in the replacement and enrichment of sandstone, siltstone, and limestone by iron oxide and hydrous oxide minerals; filling of cavities and breccia zones; and formation of gossans over massive sulfide deposits. The manganiferous iron deposits of Boston Hill and Chloride Flat, Grant County ; the Kennedy limonite mine on Glorieta Mesa, Santa Fe County ; the Copiapo (jarosite) mine, Dona Ana County ; and the gossans over oxidized pyritic deposits in many other parts of the State are examples of these types of deposits.

Colluvial and placer deposits of iron, chiefly magnetite and hematite, occur along the slopes and channels below many iron deposits as at Orogrande in Otero County, the Captain Mountains, Lincoln County, and many other places. In addition, placer deposits of heavy minerals, principally magnetite, may form from the erosion of rocks in which they are accessory minerals. Examples of these are found in Rio Arriba, Sandoval, Socorro, and Taos Counties.

The light-gray to brownish iron carbonate, siderite, while not an important source of iron, received some attention in early days of mining in New Mexico when its oxidation products, limonite and hematite, were investigated as a readily smeltable iron, as a flux, and for gold. Siderite occurs commonly throughout coal-bearing sedimentary rocks of Cretaceous age in thin beds, seams, and concretions. The siderite is too low in grade and too scattered to be classed as iron ore; however, it weathers out of the enclosing rocks and oxidizes readily to limonite and ocher which may have some local value.

Hematite, with some cassiterite, occurs as an irregular network of thin, discontinuous veinlets less than 2 inches thick in altered rhyolite. The predominant mineral is specularite, in clusters and crystals. The deposits, in Catron and Sierra Counties, are not considered an important source of iron.

Metallurgical slags at nonferrous smelter sites may someday be used as a source of iron. The slags contain approximately 35 percent iron, 0.5 percent copper, 38 percent silica, 4 percent lime, and 6 percent alumina.

Iron deposits are distributed in 21 of the 32 counties of New Mexico and a recent publication (Harrer and Kelly, 1963) lists 115 of them. The major deposits, from which all of the New Mexico iron ore production has been obtained, are those in the Boston Hill and Fierro-Hanover districts of Grant County, the Orogrande district of Otero County, the Jones-Chupadera Mesa magnetites of Socorro County, and the many magnetite-hematite deposits in the Capitan, White Oaks, Jicarilla, Tecolote, and Gallinas districts of Lincoln County. Twenty-one of the more important districts, deposits, and occurrences are shown in figure 42 and listed in table 23. Size classifications in the table follow the system of Dutton and Carr (1947), wherein large deposits contain more than 10 million long tons, intermediate deposits 2 to 10 million long tons, and small deposits less than 2 million long tons of ore. All the iron-bearing material would require some form of beneficiation to develop salable products.

Reserves of iron oxides of all classes are estimated at more than 140 million long tons. The discovery of iron formation in Rio Arriba and Taos Counties and the possibility of extensions of known deposits and additional discoveries in other areas (Jones and others, 1964) sug-

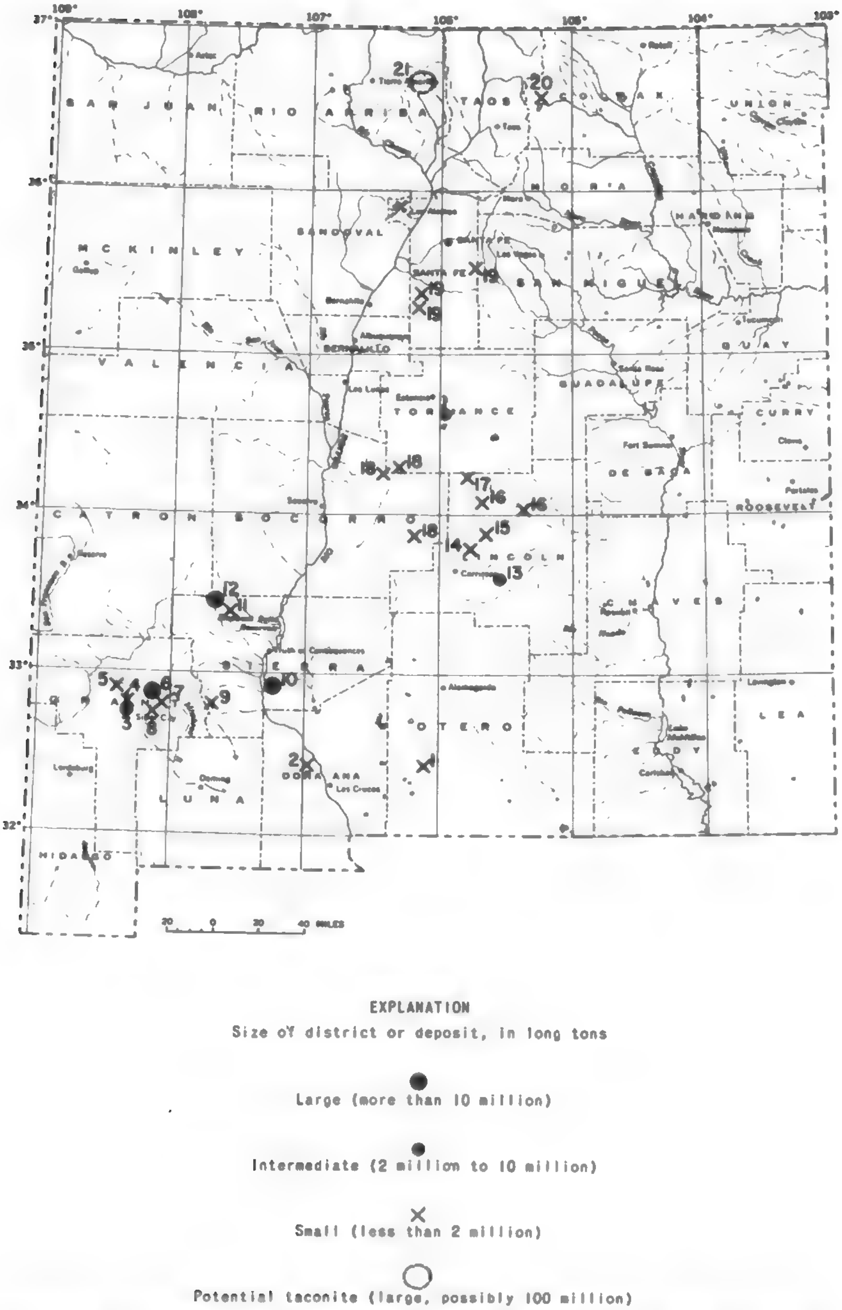


FIGURE 42.—Iron in New Mexico (numbers refer to districts, deposits, and occurrences listed in table 23).

gest that the potential resources may be much larger than the estimated reserves. The small and generally high-grade deposits individually are not considered as sources of iron ore for metallurgical use, although they may eventually provide material for other uses. The larger low-grade deposits ultimately may be sources of beneficated iron ores, with changing economic conditions. Reconnaissance studies indicate that five areas, as listed below, hold promise of larger resources of iron oxide-rich material. However, their utilization depends upon technical and economic research as well as upon different economic conditions and changing geographic patterns of iron and steel production.

1. In Grant County, the largest and most readily recoverable iron resources are contact-pyrometasomatic replacements of magnetite and hematite, both massive and disseminated, in the Fierro-Hanover-Santa Rita-Copper Flat-Bayard area, and hematites in the Glenwood and Silver City Ranges, 15 miles to the west. Possibility of further discoveries is indicated in a recent geophysical investigation (Jones and others, 1964).
2. In Sierra County, oolitic hematite, at least partly titaniferous occurs as sedimentary deposits in Bliss Sandstone in the Cabello and Black-Mimbres Mountains. Contact-pyrometasomatic magnetite-rich tactite bodies occur in Pennsylvanian limestone in the Cuchillo Range.
3. In Socorro and Torrance Counties, in the Sierra Oscura, and on Chupadera Mesa, magnetite and some hematite occur in contact-pyrometasomatic bodies associated with intrusive rocks. Known individual deposits are small, although the resource potential of the area may be fairly large.
4. In Lincoln County, magnetite and some hematite occur at many places throughout the Capitan Mountains in contact-pyrometasomatic bodies in Paleozoic limestones. Abundant, widely scattered magnetite occurrences in the Capitan Mountains suggests the desirability of detailed investigations of that area.
5. In Rio Arriba and Taos Counties, reconnaissance has established the existence of iron formation in Precambrian metasedimentary rocks in a 10-mile stretch between Hopewell, Iron Mountain, Burned Mountain, and Cleveland Gulch in Rio Arriba County (Bertholf, 1960; Harrer and Kelly, 1963) and in the Sangre de Cristo Mountains south of Cabresto Creek (Schilling, 1960, p. 23). Additional iron formation may be present in the 5,000-foot thick sequence of Precambrian rocks which extends 40 miles southeast through Dixon. The iron formation in northern New Mexico may be the most important low-grade source of impurity-free iron in New Mexico. Further investigation of it and other similar rocks in Taos County is necessary to establish its size.

MANGANESE

(By J. Van N. Dorr II, U.S. Geological Survey, Washington, D.C.)

USES, SOURCES, AND PRICE

Manganese is one of the key elements in modern industry, primarily for its properties as a desulfurizer and deoxidizer in the manufacture of steel. No adequate substitute available at reasonable price is yet known for this use, which requires about 2 million tons of 'high-grade

manganese ore per year in this country. Between 13 and 15 pounds of manganese, generally in the form of the alloy ferromanganese (manganese -± 86 percent, iron -t 14 percent, carbon -±6 percent) , are used per ton of steel (Materials Survey, National Security Resources Board).

Manganese dioxide of high purity and special properties is used in making dry batteries; known substitutes are more expensive and also are in relatively short supply in this country. Synthetic battery-grade manganese oxide is replacing natural ores to a limited extent. Manganese is also used as an alloying element, in the manufacture of glass in the chemical industry, and in other industrial processes.

The standard manganese ore of international commerce contains 46 percent or more manganese, less than 6 percent iron, and less than 0.15 percent phosphorus. The manganese to iron ratio is critical ; it must be above 3.5 :1 and should be 7:1 or higher for the manufacture of ferromanganese. Because the composition of manganese ores differs widely from deposit to deposit, ores from different sources commonly are blended to secure a uniform furnace feed. Relatively little ore containing less than 42 percent manganese is handled by major consumers.

Prices for manganese ore are negotiated on the basis of composition and the supply-demand equation ; in mid-1964 [1] 48 percent metallurgical-grade ore was quoted at 68 to 73 cents a long-ton unit (22.4 pounds) of contained manganese and 46 to 48 percent ore at 60 to 65 cents per unit.

Ferruginous manganese ore (manganese above 5 percent, iron plus manganese greater than 45 percent) also is consumed in limited quantities by the steel industry to introduce small amounts of manganese to the blast furnace. The principal sources of such ore in the United States today are the Cuyuna Range of Minnesota and the Boston Hill district of New Mexico.

PRESENT SITUATION

In 1963 manganese mines in the United States shipped 9,500 tons [2] of battery- and metallurgical-grade ore containing over 35 percent manganese, about half of which came from New Mexico (U.S. Bureau of Mines, Mineral Industries Surveys, [1] September 1964). Total shipments of ferruginous manganese ore n that year were about 350,000 tons, of which New Mexico supplied 36,736 tons. World production of plus 35 percent manganese ore is of the order of 13,500,000 tons per year, of which the United States imported in 1963 about 1,800,000 tons averaging 47.3 percent manganese, as well as about 150,000 short tons of ferromanganese (U.S. Bureau of Mines, op. cit.). The Bureau of Mines lists 29 countries as having produced more manganese ore in 1963 than the United States, a clear reflection of our limited resources of this commodity.

Because of its essentiality in the manufacture of steel and the very limited reserves within the United States, manganese has been deemed

[1] World Mining, July 1964, p. 71.

[2] In this chapter, quantitative figures on ore are given in long tons because the price of manganese ore is commonly based on long ton units of contained manganese (22.4 pounds). One long ton unit is 1 percent of contained manganese per long ton. In conversion from data originally in short tons, figures are rounded.

a strategic commodity by our Government. Much research has been devoted both to finding and evaluating domestic resources and to methods of beneficiating the low-grade ores of the United States to usable grade. Because of the need for onerous investment in plant and process, few domestic sources can compete in price with the abundant high-grade ore from foreign sources. Major world deposits are in Russia, India, Africa, and South America. The possibility of finding major new high-grade deposits within the United States seems remote in view of the efforts, both public and private, already spent in the search. The main hope for significant domestic supply lies in a breakthrough in ore dressing or metallurgical techniques in order to utilize the few large- and medium-scale low-grade deposits in the country. For these reasons an ample strategic stockpile of metallurgical-grade ore has been accumulated, largely from foreign sources.

ORE MINERALS

Useful manganese minerals are relatively few in number. Metallurgical-grade ore is always composed of one or more of the oxide minerals, cryptomelane, psilomelane, pyrolusite, hausmannite, braunite (contains 10 percent SiO_2), and wad. A few other oxide minerals are also useful. Manganese carbonate, although containing a theoretical maximum of only about 48 percent manganese (the common oxides contain more than 60 percent manganese), can be converted to oxide by calcining. Manganoan calcite, manganoan dolomite, manganoan magnesite, and manganoan siderite are commonly below ore grade and are of interest chiefly as protores from which higher grade ores are formed by natural processes. Manganese silicates, with the exception of braunite and rhodonite, are of no present interest as ore minerals. The manganese sulfide, alabandite, is too rare to be used as an ore mineral.

TYPES OF ORE DEPOSITS

Manganese ore occurs in a variety of environments. The deposits which constitute the major resources of the world and which are by far the most productive are sedimentary deposits of manganese oxides and carbonate. Such deposits may be of direct shipping grade, as are some in South America or India, but most sedimentary deposits need concentration to attain ore grade, either artificially, as in Russia, or by the natural processes of weathering and supergene enrichment, as in Ghana and Brazil. This natural concentration is most effective in tropical climates; therefore, many important high-grade ore deposits are in the tropical zone.

Another widespread type of manganese mineralization is closely associated with volcanism and magmatic processes. A multitude of small- and moderate-sized ore deposits and occurrences are associated with intrusive and extrusive rocks throughout the world ; most deposits in New Mexico are related to_ volcanism. The source of the manganese in some deposits may be the extrusive rocks themselves, in others it is deeper bodies of intrusive rock. The manganese minerals are deposited from warm or hot manganiferous fluids rising from depth. They are deposited as fillings in open fissures or brecciated areas; by replacement of limestone and to a lesser extent other rocks; as dis-

seminations in porous near-surface rocks that are locally unconsolidated; and at the surface as warm spring deposits. Manganiferous fluids of hypogene origin may also reach sedimentary basins, where their metallic content may be deposited as beds of fairly pure manganese oxide or manganese carbonate interstratified with or replacing elastic rocks, as in Morocco, where sizable deposits of this type have been formed.

Many deposits of hypogene origin contain significant and deleterious quantities of such base metals as lead, zinc, barium, or tungsten. Hypogene manganiferous deposits, both carbonates and oxides, may be arranged in zones around major deposits of base metals as in Butte, Mont., and Huelva, Spain. Such deposits may be of considerable economic interest as guides to base-metal deposits. In New Mexico, several manganiferous districts are associated spatially and perhaps genetically with silver mineralization.

Many deposits related to volcanism and essentially hypogene in origin are enriched near the surface by weathering and ground water processes. Such deposits commonly are leaner and contain less abundant oxide minerals at depth.

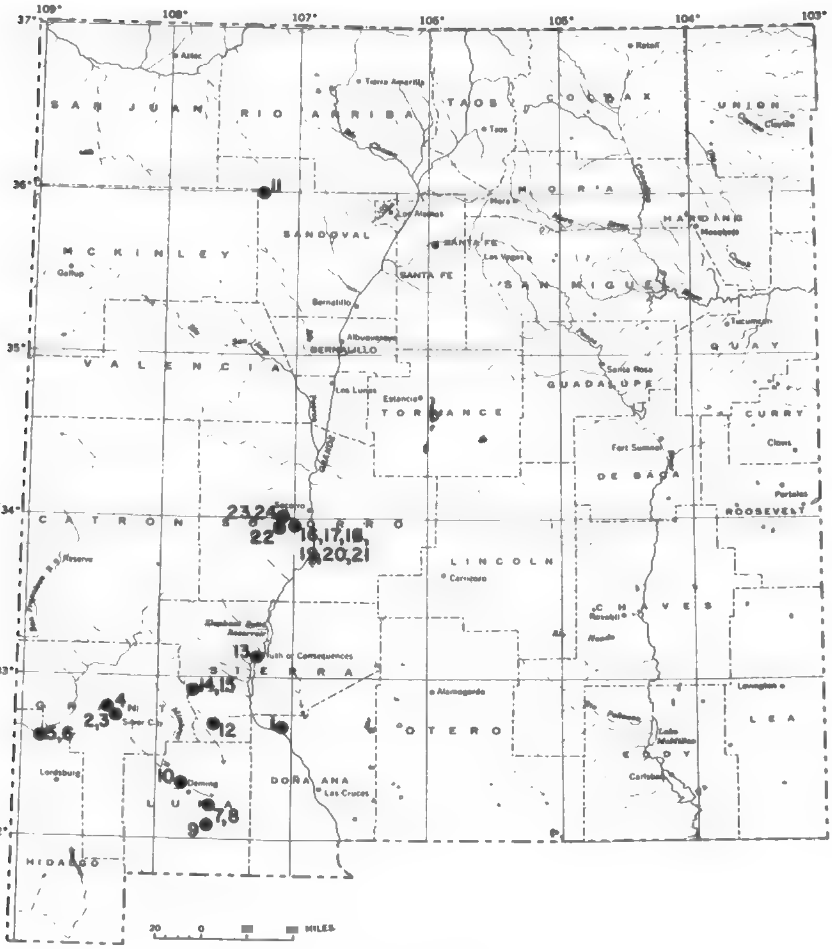
HISTORY AND DEVELOPMENT

The Boston Hill district near Silver City was the first producer of manganese ore in New Mexico, according to Wells (1918). Between 1883 and 1908, some 87,000 tons of ferruginous manganese ore were shipped for use as flux in the smelters then operating in the region. Production stopped with the closing of these smelters but started again in 1916 for the steel plant at Pueblo, Colo. In the same year, higher grade manganese ores began to be mined and shipped and, since then production both of the ferruginous manganese ore and the ore destined for ferroalloy use has continued with a few interruptions. According to Farnham (1961) and other Bureau of Mines data, cumulative production of manganiferous ore containing less than 35 percent manganese totaled about 1,900,000 tons to 1963; recorded cumulative production of ore and concentrates containing more than 35 percent manganese totaled 176,515 tons through 1963. Most of the minus-35-percent ore was ferruginous manganese ore, but much low-grade material was sold to the Deming stockpile. Farnham sketches the history of individual mines and districts to 1958 and the information need not be repeated here. Production since 1958 has dropped sharply.

MANGANESE DEPOSITS

The most complete published study of manganese ore deposits and occurrences in New Mexico was made by Farnham (1961) who visited all but 2 of the then-known 138 deposits and occurrences in the State. Much of the information in table 24 was summarized from his report. Geological work on certain important deposits and districts had been done by Lasky, Entwhistle, Creasey and Granger, Neuschel, Hewett, and others in earlier years (see bibliography and unpublished material in U.S. Geological Survey files). The writer, in 1964, inspected most of the districts and 15 of the important deposits as well as other smaller ones.

Table 24 presents information on production and occurrence of the 24 mines in the State which have shipped more than 1,000 tons each of ore or concentrate; table 25 summarizes total production by counties and gives Farnham's estimates of remaining reserves. Figure 43 shows the locations of mines and groups of mines with recorded production of more than 1,000 tons of ore and concentrates. All of the known manganese deposits, except those in Sandoval County, are of hypogene origin locally modified by weathering processes. The deposits in Sandoval County, on the other hand, occur in shale as concretionary nodules which were formed during or immediately after deposition of the host rock.



MANGANESE MINES

1. Rincon	13. Ellis
2. Boston Hill	14. Tall Pine
3. Chloride Flat	15. Iron King
4. Bear Mountain group	16. Red Hill and Red Hill extension
5. Cliff Roy group	17. Lucky Strike and Grand Canyon group
6. Consolation group	18. Gloryana
7. Manganese Valley	19. Black Canyon
8. Luna	20. Pretty Girl
9. Birchfield	21. Black Crow and San Juan
10. Starkey (Ruth) group	22. Manganese Chief
11. Landers	23. Niggerhead
12. Lake Valley	24. West Niggerhead

For detailed location, see Farnham, 1961.

FIGURE 43.—Manganese in New Mexico.

TABLE 24.—*Manganese ore production in New Mexico (mines with cumulative production greater than 1,000 tons to 1961)* [1]

County (see figure 43 for locations)	Mine	Production through 1957				Gangue minerals	Environment	Principal source of information
		Ore	Concentrates					
		Production (long tons)	Grade (percent manganese)	Production (long tons)	Grade (percent manganese)			
1. Dona Ana	Rincon	1,529	27–40			Black calcite, iron oxides, barite, quartz.	Small fissures in sandstone. Impoverished below 30 feet.	Farnham, 1961; Russel 1947.
2. Grant	Boston Hill [2]	±1,632,000	[3] 10–13			Magnesite, calcite, quartz, barite.	Supergene alteration of manganoan and ferroan magnesite replacing limestone.	Entwhistle, 1944; Farnham, 1961.
3.	Chloride Flat	3,132	[3] 11.7–16			do	do	Farnham, 1961.
4.	Bear Mountain group	1,830	±30	20	45.8	Calcite	Lenses replacing limestone near fracture zone.	Do.
5.	Cliff Roy group [2]	1,148	21–36	789	33–35	Calcite, chalcedony, gypsum	Veins in volcanic agglomerate	Do.
6.	Consolation group [2]			2,550	35	Calcite, quartz, iron oxide	Veins and fissure filling along faults in volcanic agglomerate.	Do.
7. Luna	Manganese Valley [2]	12,933	21.4	19,871	±45	do	Veins and replacement along faults in fanglomerate.	Farnham, 1961; Lasky, 1940.
8.	Luna	6,593	19.1	1,522	30–45	do	do	Do.
9.	Birchfield	1,421	22–30			Jasper, limonite, calcite, black calcite.	Replacement in limestone	Farnham, 1961.
10.	Starkey (Ruth) group.[2]			450	33–46	Calcite	Fissure filling in sheared and brecciated volcanics.	Do.
11. Sandoval	Landers			2,302	±40	Shale	Concretions in shale	Farnham, 1961; S. K. Neuschel, unpublished.

TABLE 24.—*Manganese ore production in New Mexico (mines with cumulative production greater than 1,000 tons to 1961)*[1]—Continued

County (see figure 43 for locations)	Mine	Production through 1957				Gangue minerals	Environment	Principal source of information
		Ore	Concentrates					
		Production (long tons)	Grade (percent manganese)	Production (long tons)	Grade (percent manganese)			
12. Sierra	Lake Valley [3]	4,224	±3	57,800	±25	Chert, black calcite, iron oxide.	Veins on fault and limestone replacement.	Creasey plus Granger, 1953; Farnham, 1961.
13.	Ellis	198	18	16,877	19	Sandstone	Hot spring mineralization of unconsolidated alluvium.	Creasey plus Granger, 1953; Farnham, 1961; Wells, 1918.
14.	Tall Pine [2]			[4] 1,146	40?	Calcite, quartz, iron oxides	Replacement of limestone controlled by faults and fractures.	Farnham, 1961.
15.	Iron King [2]	2,520	34–39	[4] 505	35	Quartz, calcite, iron oxides, rhodonite, rhodochrosite.	do	Do.
16. Socorro	Red Hill and Red Hill Extension (RFC).	7,000	18	[5] 59,750	±40	Rhyolite, quartz, calcite	Fissure filling in faulted and fractured rhyolite.	Do.
17.	Lucky Strike and Grand Canyon group.[2]	839	23	[5] 10,613	±40	Rhyolite, quartz, calcite?, lead.	do	Do.
18.	Gloryana [3]	1,538	20	(?)	(?)	(?)	do	Do.
19.	Black Canyon	(?)	(?)	[6] 16,060	44	Rhyolite, lead	do	Do.
20.	Pretty Girl [2]			131	42?	Rhyolite, calcite, quartz	do	Do.
21.	Black Crow and San Juan.			2,621	43	Rhyolite, andesite	do [7]	Do.
22.	Manganese Chief [3]			[8] 3,371	39	Rhyolite, black and white calcite, quartz.	do	Do.
23.	Niggerhead			3,515	±40	Rhyolite, chalcedony	do	Do.
24.	West Niggerhead [2]			[9] 986	35	Rhyolite, iron oxides, quartz	do	Do.

[1] Production data on all mines through 1957 has been published. Much production data, 1958–63, is confidential and not here included.
[2] Significant production since 1957, mostly concentrates richer than 35 percent manganese except Boston Hill. Only published data here included.
[3] Ferruginous manganese ore. Iron plus manganese > 45 percent.
[4] Production through 1959.
[5] Production after July 1958 not included.
[6] Production to end of 1958; not clear whether ore or concentrates; 1963 production, 4,787 tons, at 47.5 percent manganese, concentrates.
[7] Also in andesite.
[8] Production through November 1958.
[9] Production through Oct. 23, 1958.

Source: Data from Farnham, 1961, and U.S. Bureau of Mines statistics.

TABLE 25.—*Accumulative production of manganese ore from New Mexico, by counties, to 1963*

County	Known deposits or groups of deposits [1]	Production through 1963, long tons		Concentrates	Grade, percent manganese	Order of magnitude of reserves
		Ore	Grade, percent manganese			
1. Catron	2	67	21	----	----	Probably negligible.
2. Dona Ana	15	[3] 1,409	20–40	----	----	Few thousand tons of 10 to 20 percent ore—Farnham.
3. Grant	17	[3] 7,241	20–40+	3,491	38	Probably small reserve of +15 percent ore—Farnham.
	3	[4] 1,635,000	9–13	----	----	±1,500,000 tons, much at considerable depth—Farnham.
4. Hidalgo	11	200	35	452	±42	"Reserves not significant"—Farnham.
5. Luna	[2] 22	[5] 48,151	±21	([5])	30–40	"Ore containing 20 percent manganese largely depleted. Inferred reserves o 10–18 percent manganese not over 75,000 T"—Farnham.
6. Rio Arriba	2	None	([2])	None	([2])	"Reserves probably measurable in hundreds of tons"—Farnham.
7. Sandoval	4	----	----	±3,600	35–44	"Almost all minable ore has been exploited"—Farnham.
8. Santa Fe	2	[5] 100	----	----	----	"Several thousand tons of predominantly low-grade material"—Farnham.
9. San Juan	1	None	----	None	----	Probably negligible.[2]
10. Sierra	[2] 29	51,700	24	79,220	25	"200,000 tons of indicated and inferred ore containing 10 to 15 percent manganese"—Farnham.
11. Socorro	[2] 42	18,000	28	118,000	35–48	"Few hundred thousand tons containing 4 to 8 percent manganese plus a few tens of thousands of tons containing 20 percent manganese"—Farnham.
12. Taos	4	----	----	----	----	"Reserves measured in hundreds of tons, mostly containing less than 10 percent manganese"—Farnham.

[1] Not precise as some deposits may appear in records with 2 or more names.
[2] Particularly obscure.
[3] Probably includes some concentrates.
[4] Ferruginous manganese ore to April 1959; later data confidential except 1963, when 41,144 tons were shipped.
[5] Ore and concentrates.

Source: Data from Farnham, 1961, and U.S. Bureau of Mines statistics.

The manganiferous hypogene ores occur as (1) fissure fillings in sheeted and fracture zones in various types of volcanic rock, as in Socorro County and the Cooks Range, Luna County ; (2) replacements of limestone near faults, in many places associated with fissure filling but in others along certain favorable beds, as at Boston Hill, Lake Valley, the Birchfield group, and the Kingston district; (3) veins in fissures and faults, partly formed by replacement of rock fragments and fault gouge in coarse detrital rocks, as in the Little Florida Mountains; and (4) hot spring deposits such as the Ellis mine at Truth or Consequences. The primary ore minerals include manganiferous (black) calcite or manganoan carbonates, but are chiefly manganese oxides. All the deposits have been enriched in varying degree by weathering and reconcentration of the manganese near the surface. In some deposits the zone of enriched ore is very shallow, a few inches to tens of feet while in others it is much deeper, as at Boston Hill. Judging from the literature and old records, most of the replacement-type deposits bottomed at relatively shallow depths.

In the Boston Hill and Chloride Flat areas of Grant County, in the Kingston and Lake Valley districts of Sierra County, and in the Luis Lopez district of Socorro County, manganese ores are closely associated with ores of silver or base metals or are contaminated by lead. Several mines were worked for silver, abandoned, and then reopened for manganese. Hewett (1963) has suggested that hypogene manganese oxide deposits containing other metals serve as guides to hidden deposits of other valuable minerals.

In the Socorro area, except in the Black Canyon mine, hypogene manganese oxides occur in sheeted and breccia zones in rhyolite. These minerals coat individual fragments of rhyolite and fill fissures. The coatings range in thickness from a film to several inches or more, but are generally a fraction of an inch in thickness. The literature cites fissure fillings several feet in thickness but such thick zones of high-grade ore were not observed by the writer. The breccia zones are large, ranging up to about 150 feet across and to over 1,000 feet in length. They extend to unknown depth, the maximum depth of mining being about 100 feet.

Although the manganese oxide fillings are themselves quite high in grade, the material which must be mined is very low in grade, averaging perhaps 2 to 5 percent manganese. The manganese oxides are recovered by crushing the mined rock and concentrating the heavy manganese oxides by gravity methods or by flotation. The concentration process is controlled to a large extent by the thickness and hardness of the manganese oxide fillings and by the degree of adherence of the oxides to the sterile rock. These factors vary abruptly and unpredictably within individual deposits and between deposits. Thus, although these manganiferous breccia zones extend deeper than present mining, the generally low grade of the rock and the higher costs of mining at depth, the uncertainties in ore occurrence, and the milling problems are serious impediments to estimating possible future productivity from such deposits.

Some manganese oxide veins have been mined to depths of 450 feet or more. Among these are the Black Canyon mine, the only mine in the State producing metallurgical-grade ore in 1964, and the Manganese Valley and the Luna mines. According to D. F. Hewett (personal communication, 1964) the ore was not bottomed either in the

Manganese Valley or the Luna mines, but the mines were inaccessible when visited by the writer.

The Black Canyon mine in the Luis Lopez district exploits an ore body unlike the others now known in that district. The ore, instead of being disseminated on fracture faces in large, low-grade bodies of highly shattered volcanic rock, is concentrated in a persistent high-grade vein in a relatively narrow shear zone in massive unshattered volcanic rock. This vein has been explored for a length of 1,800 feet and to a depth of 450 feet below highest outcrop, and ranges in thickness from 0.5 to more than 10 feet of good grade ore. Shipments in 1963 averaged over 47 percent manganese. b-ood ore continues at the deepest workings.

The Boston Hill deposit of ferruginous manganese ore, the largest and most important source of manganese in the State, is believed to have been formed by supergene enrichment of hypogene replacement bodies of ferroan and manganoan magnesite in limestone. (The protore is called mesitite by Entwhistle (1944) and is a material consisting of 6$1/_2$ percent rhodochrosite, 27$1/_2$ percent siderite, and 63 percent magnesite.) Ent whistle suggests that the manganese and iron were oxidized and concentrated by descending solutions into the important ore bodies now being worked. He states that the hypogene mesitite contains about 3 percent manganese and 13 percent iron. The enriched deposit contains 8 to 15 percent manganese and 26 to 41 percent iron, indicating a considerable enrichment of manganese with respect to iron in the formation of the supergene ores. The iron and manganese oxides are too intimately intermixed for economic separation of the manganese minerals at the deposit, hence are shipped as manganiferous iron ore.

FUTURE OUTLOOK

Figure 44 illustrates the recorded production from New Mexico of manganese ore and concentrates containing more than 35 percent manganese. Until 1951, prices paid for such ore fluctuated with the world market; for much of this period manganese ore received tariff protection. Periods of high prices, such as the two World Wars, evoked larger production.

In 1951 Congress authorized payment of premium prices for domestic manganese ore and authorized Government purchase of material containing as little as 15 percent manganese delivered to Government stockpiles at Deming, N. Mex.; Wenden, Ariz.; and Butte, Mont. The price, based on $2.30 per long ton unit of contained manganese for metallurgical ore, was more than twice the world price of manganese ore of 48-percent grade. In 1952, a carload-lot program was inaugurated whereby up to 10,000 tons a year per mine of ore and concentrate containing 40 percent or more manganese was purchased at the same premium price per unit. The stockpile program was ended in late 1954, and the carload-lot program was ended late in 1959.

During these years, relatively little metallurgical-grade manganese ore was shipped from New Mexico until the low-grade stockpile program ended, although much low-grade material which could have' een concentrated to metallurgical-grade ore was produced (not shown on graph ; see table 24). Most of this low-grade material is still at Deming, and under reasonably expectable future conditions probably cannot be economically used because ores of many different types, needing various concentration techniques, are stocked together. After

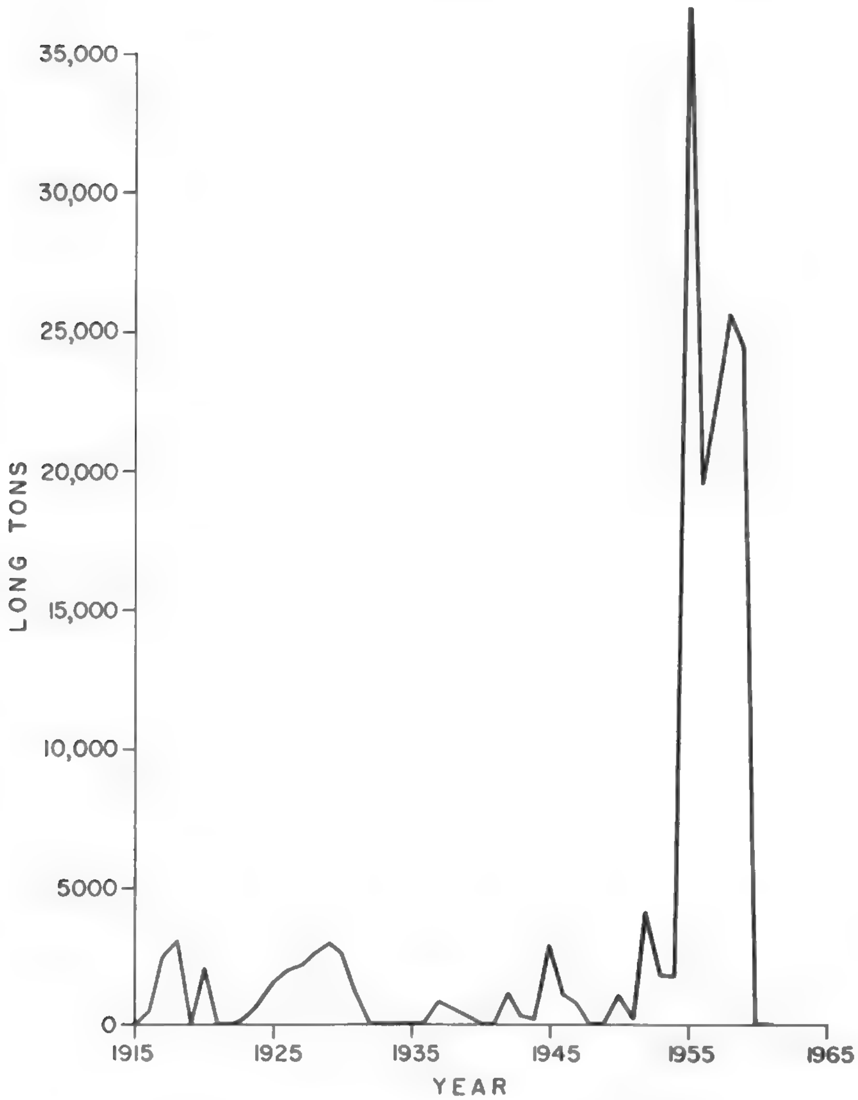


FIGURE 44.—Manganese production in New Mexico.

the stockpile program ended, low-grade ore amenable to beneficiation was concentrated to metallurgical grade for the cat'lot program and, under stimulus of the artificially high prices, production increaseA greatly. When the subsidy was ended by Presidential action at the end of 1959, production ceased. Thus for 5 years, under the stimulation of artificial prices, New Mexico produced a little more than 1 percent of the country's needs of metallurgical-grade manganese ore and concentrate. In the process, according to Farnham (see estimates of reserves in table 25), much of the more easily mined ore was extracted.

Certain tabular deposits, such as Manganese Valley, Luna County, had been mined out in areas near the surface by 1964. Ore at depth will be much more costly to mine than ore previously removed. A number of the open-cut mines will require benching and stripping before they can be returned to production, and such work will be expensive.

However, particularly in and to the west of the Luis Lopez district, Socorro County, large areas that may contain manganese deposits are covered by gravel. Other ore bodies, like the Niggerhead, which was fortuitously revealed by a canyon cutting the gravels, undoubtedly are concealed. Prospecting for such hidden bodies is most difficult and uncertain with present techniques. The original outcrop of the Black Canyon deposit was obscure and perhaps other such veins of high-grade ore in massive rather than shattered volcanic rock remain to be discovered in the Luis Lopez district, for manganese mineralization is widespread. Alteration of the volcanic host rocks, in areas near the veins, should serve as a guide for prospecting.

Great progress in the technique of concentrating low-grade ores was made during the carload-lot program. It is now technically possible to concentrate much of the lower grade ores and both recovery and costs are more favorable than a decade ago. Estimates made by knowledgeable men in the mining industry of the prices needed to renew production from now idle mines in the Socorro area ranged from 1.2 to about 3 times present world prices, with most in the lower range. Further progress in mining and metallurgy may make successful competition at world prices possible for some of the low-grade ore. There is little doubt that many of the low-grade deposits contain appreciable tonnages of manganiferous material which may become economic as techniques advance.

The continuing development of steel plants in the interior of the country and of processes for the production of synthetic battery grade manganese dioxide, as well as of other industries consuming manganese, may have a favorable long-term effect on manganese production from New Mexico ; such intracontinental plants will not have the advantage of cheap ocean transport of imported ore to the site of consumption. The production record under subsidy conditions, however, proves that only a minor percentage of the Nation's manganese needs could be produced from known deposits in New Mexico under any conditions of price or subsidy.

BERYLLIUM

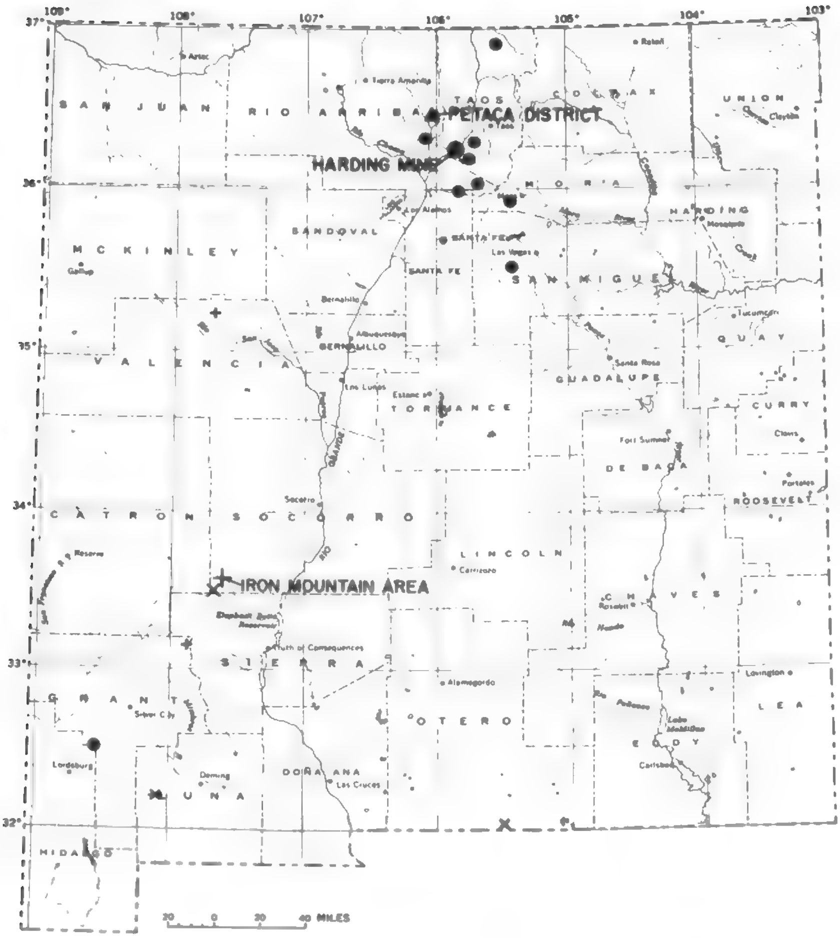
(By W. R. GrillRts, U.S. Geological Survey, Denver, Colo.)

Beryllium is a light metal of many uses, as a pure or alloyed metal or in compounds. For many years the most important use, accounting for more than half of the total production, has been as an additive to copper to make a strong, hard, fatigue-resistant alloy. This alloy approaches steel in strength and hardness, retains the electrical and thermal conductivities of copper, lacks the characteristic of steel of sparking during impact or abrasion, and is rust resistant. Beryllium-copper alloy is much used in the manufacture of tools and in springs that conduct electricity or are subjected to vibration. Alloys with nickel are also hard and strong; though less common than copper alloys, they are used in dies through which solid aluminum is pressed in the manufacture of intricate objects by the extrusion process. Alloys with aluminum and magnesium have been used to a small extent and may become increasingly important.

Beryllium metal itself was used only in a few special laboratory instruments until the onset of the atomic energy and space programs. Beryllium and its oxide are excellent moderators and reflectors of neutrons in reactors, but their use has been inhibited by high cost. Nevertheless, several special-purpose reactors have beryllium as an important ingredient. Beryllium is used in modern airborne and marine inertial guidance mechanisms because of its lightness, rigidity, and dimensional stability. Larger amounts are used in connecting rings between stages of Minuteman missiles and in heat shields of space capsules. Beryllium is also used in brake discs and in certain other parts of aircraft but the brittleness and poor behavior of the metal upon impact have prevented its large-scale use as a structural material in either manned aircraft or rockets. A possible use of the metal is as an ingredient in missile fuel or as a component of explosives.

Beryllium is consumed in much smaller amounts than many other metals; the consumption of ore by the United States increased from 1,013 tons in 1946 to an alltime high of 9,692 tons in 1960. Adequate and increasing supplies of beryllium ore have been maintained by importing the mineral beryl, which contains 10 to 14 percent BeO. This high-grade ore is obtained mainly from pegmatites in South Africa, Brazil, Argentina, India, and Australia. Only about 6 percent of the total supply is from domestic deposits. All the productive pegmatitic deposits of beryllium are small ; only 15 in the United States have yielded as much as 100 tons, and the largest mine in the world has produced a total of less than 4,000 tons. Thus, in the United States and abroad, the production has come from a large number of small mines.

The low productivity of domestic pegmatites and the smallness of pegmatitic beryllium deposits in general have caused more attention to be given to nonpegmatitic veins and other deposits since 1946. New Mexico has commonly been among the top three beryl-producing States and has been prominent because the Harding mine, in Taos County, has yielded more beryl ore than any other North American pegmatite mine ; and the tactite deposit at Iron Mountain, Sierra, and Socorro Counties, was the first American nonpegmatitic deposit to be explored for beryllium (fig. 45). These nonpegmatitic deposits



EXPLANATION

Type of deposit	Production and reserves total	
	More than 500 tons of beryl or equivalent beryl*	Less than 500 tons of beryl or equivalent beryl*
Pegmatite	●	●
Tactite and hornfels	×	×
Hydrothermal	+	+
Tactite and hydrothermal		✳
Pegmat te and hydrothermal		▲

*Equivalent beryl is the amount of beryl that would contain all of the beryllium in a deposit, regardless of the actual minerals present.

FIGURE 45.—Beryllium in New Mexico.

are particularly attractive, because some are large—the largest approaching 7,000 tons—and the grade is commonly in the tenths percent range, higher than that of pegmatitic deposits.

The most common beryllium mineral and the only one that is used as metal ore is beryl ($Be_3Al2Si_601_8$). In the last 5 years, large bodies of rock in New Mexico and other Western States have been found to contain sufficient bertrandite ($Be,Si20_2(OH)_2$) to make them potential sources of the metal. Helvite (Mn.,Be3Si2022S) has been found in large amounts in tactite at Iron Mountain, N. Mex., and has been considered to be a potential ore mineral. Three other beryllium minerals have been reported from New Mexican localities but apparently are rare. Chrysoberyl ($BeAl_20_4$) was found in northern Taos County, and gadolinite (Be2Y2FeSi20") and phenakite (Be2SiO4) have been reported to occur in eastern Rio Arriba County.

Pegmatite deposits constitute a well-defined type that is described in detail in the chapter on pegmatite minerals. On the other hand, nonpegmatitic beryllium deposits in Western United States, as a whole, are found in tactites and also in almost all genetic types of hydrothermal origin. In New Mexico beryllium minerals have been found in tactites and in both hypothermal and epithermal deposits. All of the pegmatitic deposits of the State are of Precambrian age (800 to 1,000 million years old) ; whereas the nonpegmatitic deposits are much younger, most being of Tertiary age (not more than 70 million years old.).

Pegmatitic deposits containing beryllium minerals are found mainly in a large area in north-central New Mexico, extending northward from western San Miguel County to eastern Rio Arriba County and the State line. The outstanding deposit in this area is at the Harding mine.

The pegmatite body at the Harding mine occurs as a nearly horizontal dike that dips very gently southward. The mineralized part averages 50 to 55 feet in thickness and contains beryl, lithium, and tantalum-columbium minerals for 350 feet along the strike and 650 feet down the dip (Jahns, 1951). Beryl occurs in several places in the dike, but is concentrated mostly in the wall zones, which are one-half to 5 feet thick. Exceptionally large masses of nearly pure-white or very pale-pink beryl were found just below the hanging wall of the dike. Two of these masses each yielded more than 20 tons (Montgomery, 1951). Much beryl, which had escaped notice, was recovered from the dumps that resulted from earlier mining of lithium and tantalum minerals.

The other pegmatite deposits in New Mexico are much less productive than the Harding mine, and are of two general types. Both are predominantly composed of feldspar, quartz, and muscovite, but they differ markedly in accessory minerals. One type contains accessory beryl, columbite-tantalite, and, uncommonly, lepidolite. The second type contains fluorite, rare earth minerals, beryl, and gadolinite.

The most widespread type of pegmatite in New Mexico is the quartz-feldspar-muscovite pegmatite with accessory beryl, columbite-tantalite, and lepidolite found in southern Taos County, western Mora and San Miguel Counties, and northeastern Santa Fe County. Pegmatite in northern Taos County is similar but contains chrysoberyl, which has not been reported farther south, Beryl crystals are found in these

widespread deposits in feldspathic pegmatite that makes up unzoned bodies and the crystals are dominent in wall zones and intermediate zones of zoned bodies. The crystals are generally largest and commonly most plentiful near the margins of quartz cores. The poorly known pegmatite deposits in Hidalgo and Grant Counties are apparently of this same type.

The second type of pegmatite is best developed in the two districts in east-central Rio Arriba County. In these pegmatites beryl is most common in wall zones but is also found in all other zones as well as in fracture-controlled replacement bodies (Jahns, 1946, p. 63). Gadolinite and phenakite have been reported from this area (Jahns, 1946, pp. 56-57).

Beryllium minerals have been found in nonpegmatitic rocks in a large area in southwestern New Mexico and in addition beryllium-rich igneous rocks and hornfels have been found in southern Otero County. These localities are part of a long belt that extends from the Big Bend areas of Texas and Mexico to the vicinity of Tucson, Ariz. The volcanic rocks in this belt contain abnormal concentrations of beryllium as do those in other beryllium provinces in western North America.

Beryllium minerals and rocks that contain unusual concentrations of beryllium have been found in many places in this belt; the largest concentrations found so far as those at Aguachile Mountain, Coahuila, Mexico, and at and near Iron Mountain, N. Mex.

The tactite deposits in the Iron Mountain district, Sierra and Socorro Counties, contain the largest known resources of the mineral helvite. The helvite is found in massive and layered tactite that has replaced limestone at or near contacts of small intrusive masses of rhyolite, granite, and aplite. Abundant minerals associated with the helvite are magnetite, flourite, and garnet. Less common minerals, widespread or locally abundant, include hedenbergite, hematite, idocrase, feldspar, and willemite. The helvite and associated minerals selectively replace only a few beds in the limestone, which dips eastward into the mountain. The beds are truncated by igneous rock at shallow depths, which limits the tonnage of beryllium-rich rock. Even so, the district is estimated to contain 4,500 tons with an average grade of 0.2 percent (Jahns, 1944), this being equivalent to about 3,500 tons of beryl ore or between one-third and one-half of the U.S. consumption during 1 year.

A beryllium deposit of an entirely different type was found in 1961 about 5 miles northeast of Iron Mountain. In this vicinity rhyolite and latite adjacent to a north-striking fault are brecciated and altered over an area about 1 mile long and one-half mile wide. Beryllium mineralization was greatest along the fault, where the beryllium-rich outcrop is as much as 60 feet wide and the grade locally exceeds 1 percent BeO. The beryllium mineral, bertrandite, is in the matrix of the breccia, accompanied by clay minerals, feldspar, quartz, and iron and manganese oxides. This is the first important bertrandite deposit to be found in New Mexico and represents a type of mineralization not previously known in the region.

Beryllium minerals in the Victorio Mountains, Luna County, have attracted attention because of their unusual occurrence in both veins and tactite (Holser, 1953; Warner and others, 1959, pp. 122-125) .

Beryl is abundant in quartz veins in which it is accompained by muscovite, wolframite, scheelite, fluorite, galena, and pyrite. The tactite bodies in the district contain helvite, garnet, augite, tremolite, talc, and calcite.

Helvite has been found in the base-metal deposit at the Grandview mine, Grant County (Weissenborn, 1948; Warner and others, 1959, pp. 114-116). The mineral there forms tetrahedral crystals as much as 0.1 inch across that occur in vugs together with fluorite and chalcedony. Tactite samples taken at the mine contain very little beryllium, but the lead-zinc-copper-silver ore contains larger amounts.

The Wind Mountain area, Otero County, has yielded samples that contain small to moderate amounts of beryllium (Warner and others, 1959, pp. 135-139). Some of the samples are of fine- and coarse-grained dike rocks composed of aegirine, feldspar, and nepheline ; others are of hornfels. No beryllium mineral has yet been found in the rocks.

The beryl deposit at the Sunnyside mine, Rio Arriba County, is in a vein that probably is genetically related to nearby pegmatites (Jahns, 1946, pp. 226-227). At this mine, green crystals of beryl are embedded in mica schist and are accompanied by fluorite, quartz, ilmenite, columbite, bismuth sulfide, and apatite.

A very unusual occurrence of beryl has been found near Grants, north-central Valencia County (Northrop, 1959, p. 140). The beryl forms rare tiny blue-green crystals associated with garnet, topaz, and cristobalite in cavities in a rhyolite glass at the western edge of the Mount Taylor volcanic field. This is one of only two such occurrences known in the world. The other known occurrence of beryl in rhyolite is near the large beryllium deposits at Spor Mountain, Utah. The Mount Taylor occurrence is of no present economic importance but it suggests that the general area is worthy of prospecting for beryllium.

Known reserves of beryllium ore in New Mexico are small, since very few deposits have been thoroughly explored. The potential production of the State is much higher than the reserves indicate because extensions of known deposits probably will be uncovered and new, hitherto unexploited deposits doubtless will be found. Many pegmatite dikes in the north-central part of the State have not been examined closely for beryl. The individual pegmatite deposits likely to be found in this area may yield only a few tons or less, but the total yield may become a significant fraction of U.S. beryl production.

The contrast between past production and future potential of the i nonpegmatitic deposits is much greater than that of the pegmatitic deposits. This is indicated by the fact that no beryllium ore has yet been mined from nonpegmatitic deposits; yet two of six known deposits in New Mexico contain thousands of tons of potentially minable rock. These resources may be increased substantially by discoveries of new deposits in the southwestern quarter of the State, or possibly in the Grants and Raton areas, where volcanic rocks of unusually high beryllium content are known. Although the market cannot at present absorb much ore from known nonpegmatitic deposits, the long-term prospects of beryllium mining in New Mexico. are reasonably bright.

MOLYBDENUM

(By R. U. King, U.S. Geological Survey, Denver, Colo.)

The metal, molybdenum is of vital importance as an alloying element in the ferrous metal industry. Domestic consumption m 1963 amounted to 37.5 million pounds, 80 percent of which went into the manufacture of iron and steel products. Molybdenum is a silvery-white metal with a melting point of 2,620° C., higher than all but four other metals. Molybdenum is alloyed with iron and steel to improve the properties of hardness, toughness, and resistance to corrosion. Other uses for molybdenum are in chemicals, pigments, lubricants, and fertilizers. New applications of molybdenum in special metals and alloys being developed in the nuclear-power field and in missile and aerospace technology give promise of an ever-increasing demand for this versatile metal.

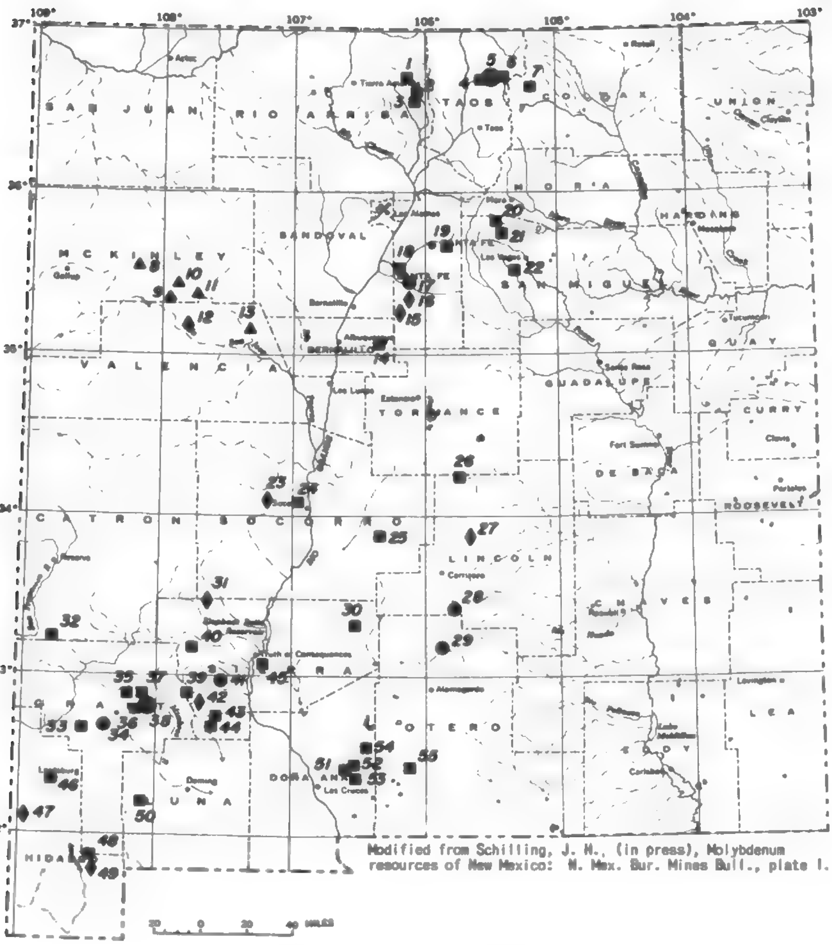
Molybdenum deposits are scattered across the central part of the State in a northeast-southwest belt (fig. 46), having been reported from more than 60 localities in 19 counties. Of these only six deposits have been mined for molybdenum and only the deposits at Santa Rita and Questa have yielded significant amounts.

The molybdenum deposits of New Mexico are of four types : porphyry or disseminated deposits, vein deposits, contact metamorphic deposits, and bedded deposits in sedimentary rocks. They are briefly described in table 26 and their locations are shown on figure 46.

The source of almost all of the molybdenum produced in New Mexico has been quartz-molybdenite vein deposits and porphyry-copper deposits from which molybdenum is recovered as a byproduct. The Questa molybdenite deposit (No. 5) , near Red River, Taos County, contains the largest known molybdenum reserves in the State. It has been described as a typical vein deposit (Vanderwilt, 1938; Schilling, 1956). Molybdenite mineralization is in fissure veins near the contact of a small stock of albite granite of probable Tertiary age with Precambrian schist and sedimentary and volcanic rocks of Paleozoic and younger ages into which the stock is intruded. Mining of the high-grade fissure veins began in 1918 and continued to 1957 when decreasing grade and number of veins at depth made further operations uneconomic.

TABLE 26.—*Molybdenum localities in New Mexico*

Map No.	County	Locality	Remarks
1	Rio Arriba	Bromide district	Molybdenite in veins and pegmatites.
2	do	Kiawa Mountain	Do.
3	do	Jarita Creek, Poso Spring, Russian Ranch.	Do.
4	Taos	Bear Canyon, Cimeros, Log Cabin.	Do.
5	do	Questa molybdenum mine	Porphyry-type molybdenite deposit, high-grade quartz-molybdenite veins. Major primary molybdenum production. Molybdenite in quartz veins.
6	do	Red River area: Copper King, Jacks and Sixes.	Molybdenite in quartz veins.
7	Colfax	Baldy tunnel	Molybdenite with copper sulfides in veins in sedimentary rocks.
8	McKinley	Smith Lake district	Ilsemannite and jordisite with uranium in bedded deposits in sedimentary rocks.
9	do	Haystack Butte	Do.
10	do	Homestake, Ambrosia Lake	Do.
11	do	Poison Canyon, Marquez mine	Do.
12	Valencia	Section 33 mine	Do.
13	do	Laguna district	Do.
14	Bernalillo	Hells Canyon area	Molybdenite in veins and pegmatite.
15	Santa Fe	San Pedro mine	Molybdenite with powellite and scheelite in contact metamorphic deposits.
16	do	Cummington Hill	Do.
17	do	Cerrillos deposit	Molybdenite with base-metal sulfides in porphyry copper deposit.
18	do	La Bajada mine	Molybdenite in complex sulfide veins in volcanic rocks.
19	do	Santa Fe district	Molybdenite in veins and pegmatite.
20	San Miguel	Azure-Rising Sun mine	Do.
21	do	Romero, Porvenir district	Molybdenite in veins and pegmatite. Small molybdenum production.
22	do	Tecolote district	Molybdenite in veins and pegmatite.
23	Socorro	Magdalena district	Molybdenite in contact metamorphic deposit.
24	do	Socorro district	Wulfenite in oxidized lead veins.
25	do	Hansonburg district	Do.
26	Lincoln	Gallinas Mountains district	Do.
27	do	Jicarilla district	Molybdenite with powellite and scheelite in contact metamorphic deposits.
28	do	Rialto claims, Nogal district	Porphyry molybdenite deposits.
29	Otero	Tularosa district	Molybdenite in porphyry copper deposits.
30	Sierra	Salinas Peak district	Molybdenite in veins and pegmatite.
31	do	Iron Mountain district	Molybdenite in contact deposits, wulfenite in oxidized lead deposits.
32	Catron	Schwarz Cabin	Molybdenite(?) in veins
33	Grant	Eccles Canyon area	Do.
34	do	Tyrone district	Molybdenite with disseminated sulfides in altered porphyry.
35	do	Portland mine	Molybdenite in veins.
36	do	Bayard area	Do.
37	do	Fierro iron deposits	Do.
38	do	Chino mines	Molybdenite associated with disseminated sulfides in porphyry copper deposit. Major byproduct molybdenum production.
39	do	Grandview mine	Molybdenite in veins.
40	Sierra	Hermosa district	Wulfenite in oxidized lead veins.
41	do	Hillsboro district, Copper Flat.	Disseminated molybdenite in porphyry-copper deposit, veins. Wulfenite mined.
42	do	Silver Tail prospect	Molybdenum in contact metamorphic deposits.
43	do	Lake Valley district	Wulfenite in oxidized lead deposits.
44	do	Macho district	Do.
45	do	Palomas Gap district	Wulfenite with vanadinite in oxidized lead veins. Small molybdenum production.
46	Hidalgo	Lordsburg district	Wulfenite in oxidized lead deposits.
47	do	Hilltop, Baker, and Scheelite prospects.	Molybdenum with scheelite in contact metamorphic deposits.
48	do	Santa Maria tunnel, Faria shaft.	Molybdenite in veins.
49	do	Eagle Point, Cactus prospects	Molybdenum in contact metamorphic deposits.
50	Luna	Irish Rose mine	Molybdenite in veins.
51	Dona Ana	Stevenson-Bennett mine	Wulfenite in oxidized lead veins, molybdenite in contact metamorphic deposits. Small molybdenum production.
52	do	Billie H-Dona Loga	Molybdenite in veins in quartz monzonite.
53	do	Texas Canyon mine	Molybdenite in veins.
54	do	Bear Canyon district	Do.
55	Otero	Orogrande district	Do.



EXPLANATION

Less than 500 short tons of molybdenum

More than 500 short tons of molybdenum

Porphyry or disseminated deposit

Molybdenum in veins and pegmatite

Molybdenum in contact metamorphic deposits

Molybdenum in bedded deposits in sedimentary rocks

FIGURE 46.—Molybdenum in New Mexico, (numbers refer to localities listed in table 26).

Molybdenum is widely distributed in the rocks of the earth's crust, averaging 2.5 parts per million (0.00025 percent). Trace amounts occur in many igneous, metamorphic and sedimentary rocks • in soils; in ground water, oceans, and hot springs • and in plant and animal tissue. It does not occur in its native state but only in combinations with sulfur, oxygen, and other metallic elements such as iron, calcium, tungsten, and lead. The most common minerals of molybdenum are molybdenite (molybdenum disulfide), powellite (calcium molybdate commonly with tungsten), wulfenite (lead molybdate), ferrimolybdite (hydrous ferric molybdate), ilsemannite (molybdenum oxy-sulfate) , and jordisite (amorphous molybdenum sulfide). Several rarer minerals of doubtful economic significance are known in which molybdenum is combined with one or more of the following metals : bismuth, cobalt, copper, magnesium, vanadium, and uranium.

Molybdenite is probably the most common naturally occurring form of molybdenum and at present is the only mineral being mined primarily for molybdenum. In the past molybdenum has been produced from deposits containing the mineral wulfenite, and in the near future molybdenum undoubtedly will be recovered from ores containing ferrimolybdite. Small quantities of molybdenum are being recovered as a byproduct from uranium ores in sandstone containing jordisite and from uranium- and molybdenum-bearing lignites.

Marketable forms of molybdenum are either molybdenite concentrate (95 percent MoS_2) or molybdenum oxide (MoO_3) which is made by roasting molybdenite concentrates.

Molybdenum was first identified in the latter part of the 18th century, but its value to the metals industries was not recognized until early in the present century when wide applications for its use were developed. There followed an intensive search for minable sources of molybdenum which resulted in the discovery of wulfenite deposits in Arizona and New Mexico and molybdenite deposits at Climax, Colo. and at Questa, N. Mex. Commercial production of molybdenum in the United States began in 1898 but was relatively small and intermittent until 1914. Since 1914 it has increased yearly with few exceptions, exceeding 500 short tons for the first time in 1925, and growing to a current annual rate of about 33,000 short tons of molybdenum. At the present time the United States accounts for about 70 percent of the world's molybdenum production.

The history of molybdenum production in New Mexico closely parallels the history of development of two of New Mexico's well-known mines : the Questa mine (No. 5, fig. 46) of the Molybdenum Corp. of American and the Chino mines (No. 38) of the Kennecott Copper Corp. The earliest production in the State was from scattered deposits in the Porvenir (No. 21), Palomas Gap (No. 45), Organ (No. 51), and Hillsboro (No. 41) districts, from which small quantities of molybdenite and wulfenite were mined during the early World War I years. The molybdenite deposits of the Questa-Red River area were first opened up during this period, and minor production was obtained from the deposits up to 1920. In 1920 the Molybdenum Corp. of of America took over the operation of the mines in Sulfur Gulch and by 1923 was producing significant quantities of molybdenite concentrates. From 1923 to 1937 production from the Questa mine amounted to slightly more than 6 million pounds of molybdenum (Vanderwilt, 1938, p. 602).

In 1939 byproduct molybdenum recovery began at the Chino mines at Santa Rita, and since then production from New Mexico has ranged from 500,000 pounds to 2 million pounds of molybdenum per year, ranking New Mexico from third to fifth in U.S. production.

Recent exploration and development work by the Molybdenum Corp. of America at the Questa mine has demonstrated that this very productive deposit is actually part of a large disseminated or porphyry type deposit (Carpenter, 1960).

The molybdenite at Questa occurs in massive quartz veins, small thin discontinuous veinlets, and as fine disseminated flakes in a hydrothermally altered and fractured zone several thousand feet wide. It is at the contact of intrusive granite with andesitic volcanic rocks. Molybdenite is the only mineral of economic importance although rhodochrosite, fluorite, and small quantities of chalcopyrite are present. The grade of the ore is low, averaging only a few tenths of 1 percent molybdenum, but large tonnages have been developed (Mining World, January 1961).

The Molybdenum Corp. of America recently has announced plans to begin mining the low-grade ore by open pit methods and to construct a mill on the property to produce molybdenite concentrates at an annual rate of 10 million pounds of molybdenum.

The Questa molybdenite deposit promises to be one of the major domestic sources of molybdenum for many years to come.

The second largest molybdenum reserves in New Mexico are in the copper porphyry deposits of the Chino Mines Division, Kennecott Copper Corp. at Santa. Rita (No. 38). At Chino small amounts of molybdenite are associated with disseminated copper sulfides in the large but low-grade ore body from which it has been recovered as a byproduct since 1939. The average molybdenite content is only about 0.01 percent (Kennecott Copper Corp., 1962) , a quantity so small that it would not ordinarily constitute an economic source of metal were it not that the deposit is minable for its copper content alone and that very large tonnages are processed daily. Additional milling facilities have recently been completed at the company's plant at nearby Hurley which will increase the efficiency of molybdenite recovery (Mining World, December 1962). Although production data are not available, a very substantial production of molybdenum can be expected from this property for the balance of this century.

The geology of the Chino area is discussed in the copper chapter of this report.

Disseminated copper-molybdenum deposits are known to occur in several other districts in the State, including Cerrillos (No. 17), Nogal (Rialto claims) (No. 28), Tularosa (No. 29) , Tyrone (No. 34), and Copper Flat (Hillsboro) (No. 41) districts. The deposits in these districts have not yielded significant quantities of molybdenum. Some molybdenite occurs with copper sulfides and pyrite in veins and is finely disseminated in altered volcanic rocks and quartz monzonite porphyry at Copper Flat (No. 14) in the Hillsboro district (Kuellmer, 1955). In the southern part of the Hillsboro district a little wulfenite was mined prior to 1917 from oxidized lead-vanadium replacement ores in limestone.

Molybdenite occurs in veinlets and as a dissmeninated deposit in an altered granitic stock at the Rialto claims (No. 28), Nogal district, Lincoln County (Griswold and Missaghi, 1964). The deposit was explored by the Climax Molybdenum Co. in 1957 and molybdenite

mineralization was found to be spotty and generally below economic grade. The property, currently being explored by the Cleveland-Cliffs Iron Co., is a potential source of molybdenum.

Vein deposits of molybdenum and molybdenum-bearing pegmatites are widespread in New Mexico, but, with the exception of the Questa deposit, have not been productive; because of the limited tonnage of material likely to be minable from individual veins or pegmatites such deposits probably do not constitute potential sources of molybdenum. A little molybdenum was produced from oxidized copper-lead-zinc veins in 1918 from the Stephenson-Bennett mine (No. 51) in the Organ district, Lincoln County (Dunham, 1935). Wulfenite is associated with vanadinite in the White Swan vein deposit in the Palomas Gap district (No. 45), Sierra County. A small quantity of wulfenite is reported to have been mined from this deposit during World War I years. The vein material is predominantly brecciated limestone containing galena and fluorite (Harley, 1934). Molybdenum occurs in a complex sulfide vein in Tertiary volcanic rocks at the Bajada mine (No. 18), Santa Fe County. The molybdenum, associated with uranium, nickel, and cobalt minerals, is present in trace amounts to as much as 0.15 percent. Molybdenum occurs in veins from a few inches to a few feet wide in the Baldy Tunnel (Baldy Deep mine) (No. 7), Colfax County. The veins are in shale at the contact of the Pierre Shale and the Raton Formation. They consist chiefly of a quartz and calcite gangue with small quantities of molybdenite and copper sulfides.

Molybdenum in contact metamorphic deposits is commonly present in the mineral molybdenite and is often associated with scheelite, bismuthinite, and copper sulfides. Deposits are found in zones of silicated limestone or tactite bodies near contacts with intrusive granitic rocks. A number of molybdenum-bearing deposits of this type are reported in the State, but none are known to contain profitably minable quantities of molybdenum.

Molybdenum in the minerals jordisite and ilsemannite occurs with uranium in bedded deposits in sedimentary rocks in parts of McKinley and Valencia Counties (Nos. 8 to 13) . Molybdenum content of deposits in the Ambrosia Lake area ranges from 0.001 to 0.7 percent. The molybdenum is irregularly distributed with respect to uranium ore bodies, commonly occurring at the margins rather than within ore bodies (Granger and others, 1961). Ordinarily the small quantities of molybdenum present in this type of deposit are detrimental because they interfere with the recovery of uranium and must be removed from the circuits during milling. However, where the uranium deposits are of sufficient size and the molybdenum content is significant, a valuable byproduct source of molybdenum may exist. According to the U.S. Bureau of Mines, two firms, Mines Development, Inc., of Edgemont, S. Dak., and Kermac Nuclear Fuels Corp., of Grants, N. Mex., recovered molybdenum from composites of uranium-bearing ores and the ash residues of uranium-bearing lignites.

In the United States current ore grades in large deposits mined primarily for molybdenum range from 0.3 to 0.5 percent molybdenite, but molybdenum is also extracted profitably as a byproduct from copper, uranium, or tungsten ores in which the molybdenum content ranges from 0.01 to 0.1 percent.

The major sources of molybdenum in New Mexico are the disseminated deposits at Questa and at Santa Rita, and future increases

in molybdenum production are likely to come from new discoveries of deposits of this type. Some contribution may also be expected from byproduct recovery of molybdenum from bedded uranium deposits in sandstone.

NICKEL AND COBALT

(By R. H. Weber, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Nickel and cobalt are essential components of a wide range of ferrous and nonferrous alloys to which they impart superior properties. The United States is the principal consumer of these metals but supplies are obtained largely from foreign sources. Both metals are of rare occurrence in New Mexico, which has no record of commercial production. Prospects for the future development of significant production of either nickel or cobalt in New Mexico are not encouraged by the available data.

NICKEL

Properties of strength, durability, resistance to corrosion and heat, low thermal expansion, magnetic character, and attractive appearance are desirable attributes of nickel alloys and coatings (Bilbrey, 1960b). The principal domestic uses reported in 1962 were: Stainless steels, 25 percent; nonferrous alloys, 24 percent; other steels, 20 percent; electroplating anodes, 14 percent; high-temperature and electrical-resistance alloys, 11 percent; and other uses 6 percent (U.S. Bureau of Mines, "Commodity Data Summaries," 1964).

Nickel is a comparatively abundant component of the earth's crust, which is estimated to contain about 0.02 percent of the element. Minable deposits are, however, sparsely distributed. Two classes of deposits are major sources of nickel : sulfide ores, such as those of Sudbury, Ontario, in which the nickel-iron sulfide mineral pentlandite is associated with pyrrhotite (iron sulfide) and chalcopyrite (copper-iron sulfide) in magmatic injection and replacement deposits; and residual lateritic ores containing hydrated nickel silicates formed by deep tropical weathering of basic igneous rocks. The deposits of New Caledonia and of Nicaro, Cuba, are representative of the lateritic type. Cobalt is a common minor associate of nickel ores.

World production of nickel in 1962 was 40,721 short tons. Imports from Canada constituted nearly 90 percent of the 118,677 short tons consumed by the United States in 1962, about 10 percent of which was supplied by one domestic producer in Oregon (Bilbrey and Long, 1963; U.S. Bureau of Mines "Commodity Data Summaries," 1964).

The only known deposits of nickel-bearing minerals of potential commercial significance in New Mexico are those of the Black Hawk mining district, about 19 miles west. of Silver City, Grant County (Gillerman and Whitebread, 1956; Gillerman, 1964). Occurrences of nickel minerals also have been cited by Northrop (1959) in the Tijeras Canyon district of Bernalillo County and the Bromide No. 2 district of Rio Arriba County, but neither the character nor extent of these deposits are known. The nickel content of manganese-oxide ores in the Luis Lopez district ranges up to 0.015 percent (Hewett and Fleischer, 1960; Hewett and others, 1963).

Active mining in the Black Hawk district was initiated in 1881 with the discovery of rich silver ore in the Alhambra mine, and terminated in 1893 as a result of the decline in the price of silver and depletion of the rich silver ore. The value of silver production during this period is estimated at between $1 and $1.5 million. Renewed interest in 1917 led to dewatering of the Black Hawk mine, and exploration of it and other properties of the district, but no production resulted and operations were halted the following year. A detailed study of the district was initiated in 1949 by the U.S. Geological Survey. Reopening of the Alhambra mine in 1957 led to shipment of a small amount of high-grade silver ore before operations were halted in 1960.

Deposits of the Black Hawk district are unique among the known mineral assemblages of New Mexico in that they contain nickel and cobalt minerals associated with native silver and small amounts of pitchblende in veins composed largely of calcite and dolomite. Ore minerals include native silver, argentite (silver sulfide), skutterudite (cobalt arsenide), and nickel-skutterudite, with minor amounts of pitchblende (uranium oxide), pyrite (iron sulfide), galena (lead sulfide), sphalerite (zinc, sulfide), niccolite (nickel arsenide), erythrite (hydrous cobalt arsenate), and annabergite (hydrous nickel arsenate) (Gillerman and Whitebread, 1956; Northrop, 1959; Gillerman, 1964). The veins are fissure fillings, principally along faults and subsidiary fractures in Precambrian quartz diorite gneiss adjacent to intrusive bodies of Late Cretaceous or early Tertiary monzonite porphyry. Although the veins are narrow (1 foot or less), they widen locally to 3 to 10 feet, have a known vertical extent of up to 600 feet, and in many instances are laterally persistent for more than 1,000 feet. Ore shoots are erratically distributed in the veins and there are sharp boundaries between the shoots and barren segments. An analysis of a 100-pound sample of high-grade silver ore from the Black Hawk mine is reported to have shown 8.92 percent nickel, 0.90 percent cobalt, 8.81 percent zinc, and 2,542 ounces per ton of silver (Gillerman and Whitebread, 1956).

COBALT

The properties of cobalt are generally similar to those of nickel, but cobalt is harder and more brittle. Resistance to oxidation, a relatively high melting point, and hardness at elevated temperatures are attributes promoting the use of cobalt in high-speed steels and in high-temperature alloys in jet engines and gas turbines. It imparts superior magnetic properties to permanent-magnet alloys (Bilbrey, 1960a, 1962). The principal domestic uses reported in 1962 were : High-temperature, high-strength alloys, 27 percent ; permanent-magnet alloys, 25 percent; nonmetallics, 10 percent ; salts and driers, 9 percent ; alloy steels, 9 percent ; alloy hard-facing rods and materials, 6 percent ; cemented carbides, 5 percent; and other uses, 9 percent (U.S. Bureau of Mines, "Commodity Data Summaries," 1964).

Despite its rather widespread occurrence in nature, cobalt is a comparatively rare component of the earth's crust, which is estimated to contain only about 0.001 to 0.002 percent of the element. Deposits containing cobalt have formed under the influence of a wide range of geological processes that include magmatic segregation, hydrothermal vein filling and replacement, and the lateritic weathering of basic igneous rocks. Cobalt is most commonly a minor associate of other

metals, especially copper, nickel, iron, silver, and lead. As a consequence, the metal is recovered largely as a byproduct of other metal-mining and refining operations, few deposits having proved workable primarily for their cobalt content. Important cobalt-bearing minerals include a number of arsenides, sulfarsenides, sulfides, and their oxidation products. The geology and mineralogy of cobalt is treated more fully by Bastin (1939), Young (1948), Vhay *in* Davis and others (1952), and Bilbrey (1960a, 1962) .

World production of cobalt in 1962 (exclusive of the Soviet Union and Red China) was 16,067 short tons. The United States consumed 5,634 short tons in 1962, a new record 5 percent higher than the previous record in 1952 (Bilbrey and Clarke, 1963; U.S. Bureau of Mines, "Commodity Data Summaries," 1964). Domestic production in 1962 was not reported inasmuch as it came from a single producer in Pennsylvania. Mine production in the United States from 1940 to the present has ranged from 67 to 2,422 short tons, largely from magnetic iron ores in Pennsylvania, lead ores in Missouri, and copper-cobalt ores in Idaho (Bilbrey, 1962). Major imports in recent years have come from the Republic of the Congo, Belgium-Luxembourg, and West Germany.

The principal known deposits of cobalt in New Mexico are those of the Black Hawk district in Grant County, which were worked only for their silver content (summarized under nickel). Smaltite (Cobalt-nickel arsenide) was identified by R. A. Zeller, Jr., among the metallic minerals in the Creeper mine, Sylvanite district, Hidalgo County (Northrop, 1959). Very small amounts of cobalt have been detected spectrographically in manganese-oxide ores in a number of localities, the amounts ranging up to 0.15 percent in the Red Hill deposit, Luis Lopez district, Socorro County (Hewett and others, 1963). Cryptomelane and hollandite from the Black Feather claims in the same district yielded 0.59 percent cobalt oxide (CoO) by chemical analysis (Hewett and Fleischer, 1960).

URANIUM

(By L. S. Hilpert, Salt Lake City, Utah)

REVIEW OF INDUSTRY

Uranium consists of a mixture of the isotopes U_{238}, U_{235}, and U_{234}. The isotope U_{238} constitutes more than 99 percent of natural uranium and can be converted to fissionable plutonium. The naturally fissionable U_{235} isotope and plutonium are the principal ingredients in fuel for nuclear reactors and in weapons; these are the major uses for uranium. Minor amounts of uranium are also used in the chemical, ceramic, and electrical industries.

Consumption of uranium was small prior to World War II, but with the development of the nuclear bomb it became a metal of great strategic importance. During the late 1940's and early 1950's, because of the domestic shortage, the United States obtained its supply mostly from foreign sources, first largely from the Belgian Congo and then from Canada. By the mid-1950's the domestic supply could largely satisfy domestic needs, and foreign purchases were gradually

decreased. By 1963 domestic producers supplied 62 percent of total purchases, the remainder being supplied mostly by Canada and the Republic of South Africa (Baroch, 1964).

Uranium has been a commodity of great importance to New Mexico since the early 1950's. Although uranium minerals have been known in New Mexico for many years (Jones, 1904, pp. 113, 186, 342, 344) they were little more than curiosities until carnotite deposits were discovered in 1918 west of Shiprock, San Juan County, and uraniferous minerals were discovered about 1920 in the White Signal and Black Hawk districts, Grant County (Hess, 1922, p. 416). A small amount of ore was mined from these deposits for pharmaceutical purposes (Lovering, 1956, p. 329). In the period from 1942 to 1944 a few thousand tons of ore were mined from the Shiprock area for the vanadium content. Subsequently, during 'World War II, some of the mill tailings of this ore were re-treated for uranium recovery.

In 1948 prospecting was stimulated by the U.S. Atomic Energy Commission with the ore-buying schedule announced in Circular 5. New deposits were found shortly thereafter in many parts of the State, notably in limestone at the outcrop near Grants, McKinley County, in 1950; in sandstone at the outcrop near Laguna,Valencia County, in 1951 (the Jackpile deposit) • and in large subsurface deposits in sandstone near Ambrosia Lake, McKinley County, in 1955. Development of these deposits and others was rapid ; the output in 1956 exceeded 1 million tons of ore and it climbed until it reached a peak in 1960 of about 3.8 million tons of ore (table 27).

TABLE 27.—*Uranium ore production in New Mexico*

Years	Short tons [1]	Grade (percent U_3O_8)	Value [1] [2]
1918–41	Negligible		
1942–44	([3])		[4] Negligible
1945–49	Negligible		
1950	[5] 6,000	[5] 0.21	$100,000
1951	[5] 2,000	[5] .24	[5] 61,000
1952	[5] 23,000	[5] .22	[6] 546,500
1953	[5] 85,000	[5] .25	[6] 2,067,000
1954	[5] 196,000	[5] .36	[6] 6,303,000
1955	[5] 262,000	[5] .25	[7] 5,270,000
1956	1,105,183	.26	24,086,234
1957	1,175,742	.22	20,538,086
1958	1,888,499	.26	32,264,000
1959	3,269,826	.21	53,463,000
1960	3,793,494	.21	61,827,000
1961	3,631,036	.22	62,482,000
1962	3,478,238	.23	63,504,000
1963	[8] 2,304,577	.22	[8] 41,372,000
Total (rounded) and average	21,225,000	.23	374,000,000

[1] Data from U.S. Bureau of Mines Minerals Yearbook, except as noted.
[2] F.o.b. mine value, including base price, grade premiums, and development allowance ; vanadium excluded.
[3] Few thousand.
[4] Mined for vanadium ; small amount later reprocessed for uranium recovery.
[5] Compiled from file data, available by courtesy of U.S. Atomic Energy Commission.
[6] Calculated on base price, grade premiums, and development allowance for yearly average grade plus following production bonuses: 1951, $21,401 ; 1952, $134,789 ; 1953, $303,163 ; and 1954, $187,685 (J. A. Patterson, oral communication, September 1964).
[7] Prorated estimate based on July–December 1955 tonnage, grade, and ore value figures, from Minerals Yearbook.
[8] U.S. Bureau of Mines Mineral Industry Surveys, June 1964.

[1] See Atomic Energy Commission Regulations, pt. 60, Domestic Uranium Program Circulars 1 to 6, inclusive, Apr. 9, 1948, June 15, 1948, Feb. 7, 1949, and June 27, 1951.

The output from New Mexico has been of vital importance to the Nation as well as to the State. In the 1957-63 period uranium production in New Mexico was 40 percent of the total for the country. The dollar values of the uranium ores mined have ranged from about 4 and 3 percent of the State's total mineral output, in 1956 and 1957, respectively, up to more than 9 percent in 1960 and 1962. Although there has been a general decline in output since 1960, New Mexico will probably continue to hold the same general proportion of total U.S. output for at least the next few years. The recent decline has resulted primarily from the saturated uranium market. Fringe benefits have been permitted to lapse, restrictions have been imposed on mine allotments, and the price paid for mill concentrates has been reduced. The bonus paid for initial production of uranium ores from new mines terminated February 28, 1957, and payments made for contained V_2O_5 were discontinued on ores that were too low in vanadium for efficient vanadium recovery. In 1962, a stretchout program for domestic uranium procurement for the period from January 1, 1967, to December 31, 1970, was announced. It provides for deferring delivery to 1967 and 1968 of some uranium concentrates which were originally contracted for delivery before 1967, and for purchase of an additional amount of concentrates in 1969 and 1970 equal to the amount deferred to 1967 and 1968. In 1969 and 1970 the maximum price is to be \$6.70 per pound of contained U_3O_8. This general cutback resulted in the closing in 1963 of one uranium mill in New Mexico, leaving four operating mills and one on standby status in 1964. The combined rated capacity of these mills is about 10,000 to 11,000 tons of ore per day.[1]

PENECONCORDANT DEPOSITS

Uranium deposits in New Mexico occur in rocks of many ages and lithologic types. Two general types of deposits, peneconcordant and vein, occur in New Mexico. The most abundant, largest, and most productive are the peneconcordant deposits (Finch, 1959a). These occur in sedimentary rocks and are nearly concordant (parallel) to the bedding. The deposits are found most often in thick fluvial sandstone and conglomeratic sandstone which has been bleached gray or stained brown. Such deposits have been referred to as sandstone-type deposits. To a lesser extent, peneconcordant deposits occur in lignite and carbonaceous shale, and in limestone. The deposits are roughly tabular to lenslike, tending to be elongate and parallel, or nearly so, to such sedimentary features as sandstone lenses and bedding structures. Most of the deposits are restricted to certain favorable stratigraphic units, where they occur in clusters, and these clusters in turn tend to occur in belts. The recognition of these features is useful in exploration for hidden deposits and in making resource appraisals. Size of the deposits ranges from local masses that contain less than a ton of material to large masses that contain as much as several million tons. The grade ranges from trace amounts to several percent uranium but the average grade of the ore is about 0.25 percent U_3O_8.

The mineralogy is complex and varies between deposits, depending

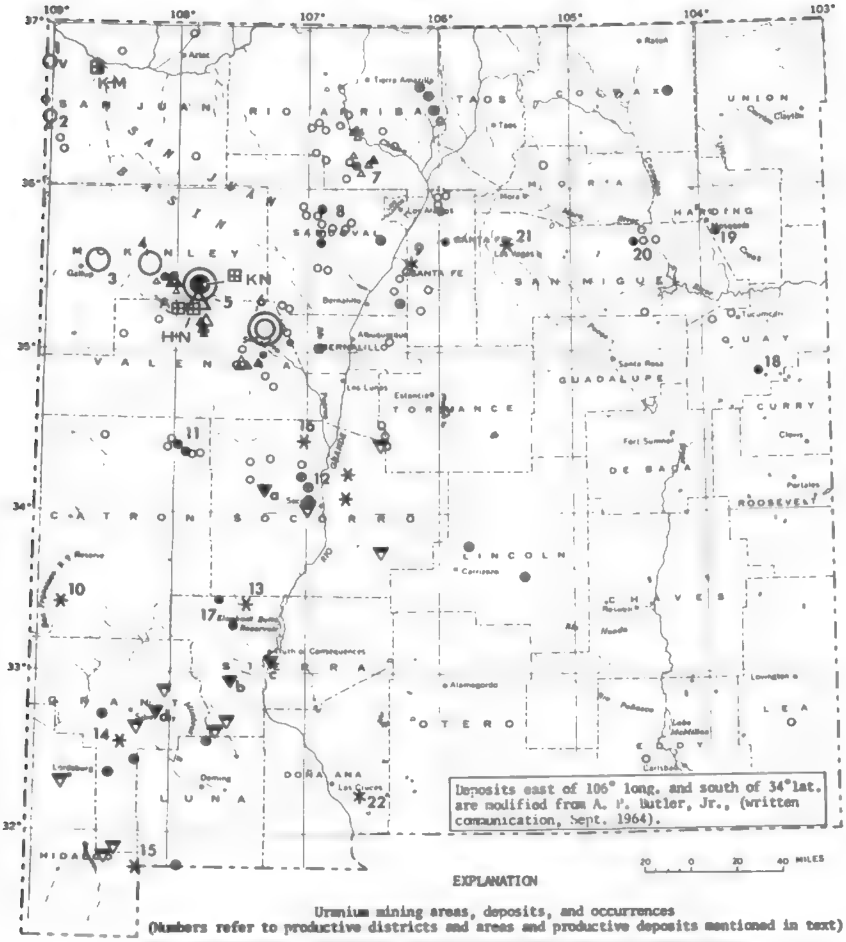
[1] U.S. Atomic Energy Commission Press Release 356, Washington, D.C., and Grand Junction, Colo., Nov. 17. 1962.

on the relative contents of uranium and vanadium and copper and the degree of oxidation. The vanadiferous deposits generally range in uranium to vanadium ratio from about 1 :1 to 1 :10 and contain traces of copper and other metals, but in general the copper content is less than in the nonvanadiferous deposits. The so-called nonvanadiferous deposits actually contain small amounts of vanadium and also minor amounts of copper and other metals, but locally contain as much as several percent copper. Those that have yielded copper ore have been referred to as red beds copper deposits.

Near the surface, the vanadiferous deposits consist largely of the uranyl vanadates, carnotite and tyuyamunite, and various other vanadium minerals; and the nonvanadiferous deposits contain the uranium hydrous oxide, becquerelite. Where much copper is present, the minerals are commonly the hydrous phosphate (torbernite) and hydrous sulfate (johannite) of copper and uranium and hydrous carbonates of copper.

Below the surface and generally below the water table, the unoxidized analogs of these minerals are principally uraninite (pitchblende), coffinite, montroseite, and micaceous vanadium silicates in the vanadiferous deposits; uraninite or coffinite in the nonvanadiferous deposits; and uraninite and variable amounts of iron and copper sulfides where much copper is present. The mineralogy is discussed more completely by Hess (1933), Botinelly and Weeks (1957), Finch (1959b), Garrels and Larson (1959), Laverty and Gross (1956), Truesdell and Weeks (1959), and Granger (1963) .

Peneconcordant deposits in New Mexico occur in sedimentary rocks ranging in age from Paleozoic to Tertiary and occurring in many stratigraphic units. The important ones, however, are largely confined to rocks of Jurassic age in the northwestern part of the State. These and the less important ones are reviewed in ascending stratigraphic order. The productive districts, areas, and deposits are identified by number on figure 47 and most of the individual mines are listed in tables 28 to 30; others are named in the text. ITnproductive deposits or occurrences are shown by symbol only and, when not cited in the text, can generally be identified and located in Hilpert and Corey (1955, pp. 104-118), Butler, Finch, and Twenhofel (1962), and Anderson (1955).



EXPLANATION

Uranium mining areas, deposits, and occurrences
(Numbers refer to productive districts and areas and productive deposits mentioned in text)

Type of deposits	Host rock	Tons of ore shipped through 1963					
		>10,000,000	1,000,000-10,000,000	100,000-1,000,000	10,000-100,000	1-10,000	Occurrence 1/
Deposits penecon-cordant with sedi-mentary features of the enclosing rocks	Sandstone, silt-stone, and carbonaceous shale 2/	◉	◎	○	○ 3/	•	°
	Limestone 2/			△	△	▲	△
Veins, breccia zones, stockworks, and related types	(See text)					*	•

1/ Material containing at least 0.01 percent U_3O_8 or recognizable uranium minerals and 0.01 or more eU_3O_8.
2/ In McKinley and Valencia Counties, individual productive deposits are not numbered or described and are not shown within areas of large symbols.
3/ A "v" by symbol (○v) indicates deposits are vanadiferous.

Vanadate deposits
▼ Reported production
▽ No reported production
(Letters refer to districts mentioned in text)

■ Uranium mill operating in 1964
(A, The Anaconda Co.; K-M, Kerr-McGee Oil Industries; KN, Kermac Nuclear Fuels Corp.; H-N, Homestake-Sapin New Mexico Partners)

FIGURE 47.—Uranium and vanadium in New Mexico.

TABLE 28.—*List of mines in the Todilto limestone*

Name	*Location (section, township, and range, New Mexico Principal Meridian)*
McKinley County:	
Ambrosia Lake district (locality 5, fig. 47):	
Barbara J. No. 1.	NE¼ sec. 30, T. 13 N., R. 9 W.
Barbara J. No. 3.	NE¼ sec. 30, T. 13 N., R. 9 W.
Dalco No. 1	NW¼ sec. 30, T. 13 N., R. 9 W.
Faith	NW¼ sec. 29, T. 13 N., R. 9 W.
Flat Top No. 3.	SE¼ sec. 30, T. 13 N., R. 9 W.
Flat Top No. 4.	SE¼ sec. 30, T. 13 N., R. 9 W.
Hanosh	NE¼ sec. 26, T. 13 N., R. 10 W.
Haystack	NW¼ sec. 19, T. 13 N., R. 10 W.
Haystack No. 2.	Center SW¼ sec. 13, T. 13 N., R. 11 W.
Manol	SW¼ sec. 30, T. 13 N., R. 9 W.
Red Point lode.	NW¼ sec. 16, T. 13 N., R. 10 W.
Rimrock	SW¼ sec. 30, T. 13 N., R. 9 W.
Section 18, SW¼	SW¼ sec. 18, T. 13 N., R. 10 W.
Section 18, SE¼	SE¼ sec. 18, T. 13 N., R. 10 W.
Section 19, NE¼	NE¼ sec. 19, T. 13 N., R. 10 W.
Section 23	S½SE¼ sec. 23, T. 13 N., R. 10 W.
Section 24	NE¼ sec. 24, T. 13 N., R. 11 W.
Section 25	Sec. 25, T. 13 N., R. 10 W.
Section 31	N½ sec. 31, T. 13 N., R. 9 W.
Section 33	Sec. 33, T. 14 N., R. 9 W.
Smith Lake district, (locality 4, fig. 47):	
Billy the Kid	NE¼ sec. 19, T. 14 N., R. 11 W.
Glover	NW¼ sec. 20, T. 14 N., R. 11 W.
Lawrence Elkins.	NE¼ sec. 24, T. 14 N., R. 12 W.
Section 19 (Greer, Warren, & McCormack).	NE¼ sec. 19, T. 14 N., R. 11 W.
Section 19 (Maddox & Teague).	Sec. 19, T. 14 N., R. 11 W.
Section 21	SW¼ sec. 21, T. 14 N., R. 11 W.
T. No. 2	SW¼ sec. 28, T. 14 N., R. 11 W.
T. No. 10	SW¼ sec. 28, T. 14 N., R. 11 W.
Tom Elkins	SE¼ sec. 24, T. 14 N., R. 12 W.

TABLE 28.—*List of mines in the Todilto limestone*—Continued

Name	*Location (section, township, and range, New Mexico Principal Meridian)*
Rio Arriba County:	
Locality 7 (fig. 47):	
Wasson	NE¼ sec. 28, T. 23 N., R. 4 E.
Valencia County:	
Ambrosia Lake District (locality 5, fig. 47):	
Black Hawk	SE¼ sec. 4, T. 12 N., R. 9 W.
Bunney	SE¼ sec. 4, T. 12 N., R. 9 W.
Cedar No. 1	SE¼ sec. 20, T. 11 N., R. 9 W.
Christmas Day	NE¼ sec. 4, T. 12 N., R. 9 W.
Double Jerry	NW¼ sec. 3, T. 12 N., R. 9 W.
F-33	SE¼ sec. 33 and SW¼ sec. 34, T. 12 N., R. 9 W.
Gay Eagle	SE¼ sec. 4, T. 12 N., R. 9 W.
La Jara	SE¼ sec. 15, T. 12 N., R. 9 W.
Last Chance	NE¼ sec. 8, T. 12 N., R. 9 W.
Lone Pine No. 3.	NE¼ sec. 8, T. 11 N., R. 9 W.
Red Bluff No. 3.	NE¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 5	NE¼ and NW¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 7.	SW¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 8	SE ¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 9.	NE¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 10.	SE ¼ sec. 4, T. 12 N., R. 9 W.
Section 9	NW¼ sec. 9, T. 12 N., R. 9 W.
Tom 13	SE¼ sec. 4, T. 11 N., R. 9 W.
UDC No. 5	SE¼ sec. 4, T. 12 N., R. 9 W.
Zia [1]	SW¼ sec. 15, T. 12 N., R. 9 W.
Laguna district (locality 6, fig. 47):	
Crackpot	NW¼ sec. 8, T. 8 N., R. 5 W.
Paisano	NW¼ sec. 16, T. 8 N., R. 6 W.
Sandy [1]	SE¼ sec. 22, T. 9 N., R. 5 W.

[1] Partly in Entrada Sandstone.

Name	*Location (section, township, and range, New Mexico Principal Meridian)*
Harding County:	
Locality 19 (fig. 47):	
Polita No. 2	Sec. 5, T. 17 N., R. 29 E.
McKinley County:	
Ambrosia Lake district (locality 5, fig. 47):	
Ann Lee	Sec. 28, T. 14 N., R. 9 W.
Beacon Hill	SE¼ sec. 18, T. 13 N., R. 9 W.
Blue Peak	NE¼ sec. 24, T. 13 N., R. 10 W.
Bob Cat	NE¼ (?) sec. 24, T. 13, N., R. 10 W.
Bucky	SE¼ sec. 14, T. 14 N., R. 10 W.
Cliffside	SW¼ sec. 36, T. 14 N., R. 9 W.
Dog Incline No. 1.	NE¼ sec. 20, T. 13 N., R. 9 W.
Dysart No. 1	S½ sec. 11, T. 14 N., R. 10 W.
Hogan	S½ sec. 14, T. 13 N., R. 9 W.
Malpais	Center S½N½ sec. 20, T. 13 N., R. 9 W.
Marquez	Center sec. 23, T. 13 N., R. 9 W.
Mesa Top No. 7 (Moe).	Center W½ sec. 20, T. 13 N., R. 9 W.
Mesa Top No. 18 and 20.	SW¼ sec. 20, T. 13 N., R. 9 W.
Pat	NE¼ sec. 4, T. 13 N., R. 10 W.
Poison Canyon.	NE¼ and SE¼ sec. 19, T. 13 N., R. 9 W.
Sandstone	Sec. 34, T. 14 N., R. 9 W.
Centennial (Section 8).	NW¼ sec. 8, T. 13, N., R. 9 W.
Section 10	E½ sec. 10, T. 14 N., R. 10 W.
Section 15	SE¼ sec. 15, T. 14 N., R. 10 W.
Section 17	S½ sec. 17, T. 14 N., R. 9 W.
Section 21	NE¼SW¼ sec. 21, T. 13 N., R. 9 W.
Section 22	E½ sec. 22, T. 14 N., R. 10 W.
Sectiou 23	Sec. 23, T. 14 N., R. 10 W.
Section 24	Sec. 24, T. 14 N., R. 10 W.
Section 25	Sec. 25, T. 14 N., R. 10 W.
Section 30 (Kermac)	Sec. 30, T. 14 N., R. 9 W.
Section 32	N½ sec. 32, T. 14 N., R. 9 W.
Section 33	Sec. 33, T. 14 N., R. 9 W.
Section 36	NE¼ sec. 36, T. 14 N., R. 10 W.
Taffy (Bonanza.	Secs. 11, 14, 15, T. 12 N., R. 9 W.
Gallup district (locality 3, fig. 47):	
Church Rock	NE¼ sec. 17, T. 16 N., R. 17 W.
CD & S	SE ¼ sec. 35, T. 16 N., R. 17 W.
Foutz No. 1	NW¼ sec. 4, T. 15 N., R. 16 W.
Foutz No. 2	NE¼ sec. 5, T. 15 N., R. 16 W.
Foutz No. 3 YJ.	SE¼ sec. 31, T. 16 N., R. 16 W.
Westwater No. 1.	S½ sec. 12, T. 15 N., R. 16 W.
Smith Lake district (locality 4, fig. 47):	
Alta	SW¼ sec. 5, T. 14 N., R. 11 W.
Black Jack No. 1.	Sec. 12, T. 15 N., R. 13 W.
Black Jack No. 2.	Sec. 18, T. 15 N., R. 13 W.
Evelyn	NW¼ sec. 9, T. 14 N., R. 11 W.
Francis	NW¼ sec. 8, T. 14 N., R. 11 W.
Silver Bit No. 7.	NE¼ sec. 10, T. 14 N., R. 12 W.
Silver Bit No. 15.	NE¼ sec. 10, T. 14 N., R. 12 W.
Silver Bit No. 18.	NE¼ sec. 10, T. 14 N., R. 12 W.

TABLE 29.—*List of mines in the Morrison Formation*—Continued

Name	*Location (section, township, and range, New Mexico Principal Meridian)*
Sandoval County:	
Locality 8 (fig. 47):	
Collins	Sec. 25, T. 17 N., R. 1 W. (projected unsurveyed land).
San Juan County:	
Chuska district (locality 2, fig. 47):	
Carl Yazzie No. 1.	NW¼ sec. 30, T. 25 N., R. 20 W.
Castle T'sosie	SE¼ sec. 11, T. 25 N., R. 21 W.
Dench Nezz	NE¼ sec. 18, T. 25 N., R. 20 W.
Dench Nezz No. 2.	NE¼ sec. 18, T. 25 N., R. 20 W.
Dench Nezz No. 3.	NW¼ sec. 18, T. 25 N., R. 20 W.
Enos Johnson	SW¼ sec. 19, T. 25 N., R. 20 W.
Enos Johnson No. 1.	NW¼ sec. 19, T. 25 N., R. 20 W.
Enos Johnson No. 2.	NW¼ sec. 19, T. 25 N., R. 20 W.
Enos Johnson No. 3.	NW¼ sec. 19, T. 25 N., R. 20 W.
H. B. Roy No. 2.	NE¼ sec. 36, T. 25 N., R. 21 W.
Horace Ben No. 1.	SE¼ sec. 19, T. 25 N., R. 20 W.
Joe Ben No. 1	NW¼ sec. 13, T. 25 N., R. 21 W.
Joe Ben No. 3	NE¼ sec. 24, T. 25 N., R. 21 W.
John Joe No. 1.	SE¼ sec. 11, T. 25 N., R. 21 W.
Kee Tohe	SE¼ sec. 11, T. 25 N., R. 21 W.
Shiprock district (locality 1, fig. 47):	
Alongo	SW¼ sec. 25, T. 29 N., R. 21 W.
BB (Lewis Barton).	Uncertain location.
BBB (Barton & Begay).	Do.
Begay No. 1	NW¼ sec. 24, T. 29 N., R. 21 W.
Canyon No. 1	NW¼ sec. 2, T. 29 N., R. 21 W., (may be in Arizona).
Canyon View	Uncertain location.
Carrizo No. 1	Do.
Cottonwood Butte.	Do.
Junction	NE¼ sec. 24, T. 29 N., R. 21 W.
King No. 2	NW¼ sec. 26, T. 30 N., R. 21 W.
King No. 6	SW corner sec. 11, T. 30 N., R. 21 W.
King Tutt	SE¼ sec. 23, T. 29 N., R. 21 W.
King Tutt No. 1.	SW¼ sec. 24, T. 29 N., R. 21 W.
King Tutt Point.	Uncertain location.
Lone Star	SW¼ sec. 35, T. 30 N., R. 21 W.
Lookout Point.	SE¼ sec. 14, T. 29 N., R. 21 W.
Nelson Point	NW¼ sec. 23, T. 29 N., R. 21 W.
Rattlesnake No. 6.	Uncertain location.
Red Wash Point.	Do.
Rocky Flats	SW¼ sec. 14, T. 30 N., R. 21 W.
Rocky Flats No. 2.	SE¼ sec. 26, T. 30 N., R. 21 W.
Rocky No. 2	Uncertain location.
Salt Canyon	NE¼ sec. 14, T. 29 N., R. 21 W.
Sam Point	Uncertain location.

TABLE 29.—*List of mines in the Morrison Formation*—Continued

Name	*Location (section, township, and range, New Mexico Principal Meridian)*
San Juan County—Continued	
Shiprock district—Continued	
Shadyside	Center N½ sec. 23, T. 29 N., R. 21 W.
Shadyside No. 2.	Center N½ sec. 23, T. 29 N., R. 21 W.
Tent	NE¼ sec. 23, T. 29 N., R. 21 W.
Valencia County	
Ambrosia Lake district (locality 5, fig. 47):	
San Mateo (section 30).	Sec. 30, T. 13 N., R. 8 W.
Laguna district (locality 6, fig. 47):	
Chaves	SE¼ sec. 22, T. 10 N., R. 3 W.
Jackpile	Parts of secs. 26 and 35, T. 11 N., R. 5 W., and center N½ sec. 2, T. 10 N., R. 5 W.
M-6	SW¼ sec. 19 and NW¼ sec. 30, T. 11 N., R. 4 W.
Paguate	Secs. 4 and 5, T. 10 N., R. 5 W., and sec. 33, T. 11 N., R. 5 W.
St. Anthony	NE¼NW¼ sec. 29, T. 11 N., R. 4 W.

NOTE.—In the Shiprock and Chuska districts, the land is unsurveyed and the mine locations are based on a projected land net.

TABLE 30.—*List of Mines in the Dakota sandstone*

Name	*Location (section, township, and range, New Mexico Principal Meridian)*
McKinley County:	
Ambrosia Lake district (locality 5, fig. 47):	
Junior	NE¼ sec. 4, T. 13 S., R. 10 W.
Sec. 5 (Westvaco).	Sec. 5, T. 13 N., R. 10 W.
Silver Spur No. 1.	Sec. 31, T. 14 N., R. 10 W.
Silver Spur No. 5.	NE¼ sec. 31, T. 14 N., R. 10 W.
Small Stake	S½SW¼ sec. 31, T. 14 N., R. 10 W.
Gallup district (locality 3, fig. 47):	
Becenti	NW¼ sec. 28, T. 15 N., R. 17 W.
	SE¼ sec. 4, T. 15 N., R. 16 W.
Christian 16 (U).	
Diamond No. 2.	NE¼ sec. 33, T. 15 N., R. 17 W.
Hogback	NE¼ sec. 12, T. 15 N., R. 18 W.
Santa Fe Christ (sec. 3)	SW¼ sec. 3, T. 15 N., R. 16 W.
Sandoval County:	
Locality 8 (fig. 47):	
Butler Bros. No. 1.	NE¼ sec. 23, T. 19 N., R. 1 W.

Deposits in Pennsylvanian, Permian, and Triassic rocks.—Deposits in rocks of Pennsylvanian to Triassic age are mineralogically similar, are generally nonvanadiferous, and are referred to as red beds copper deposits where worked for copper. These deposits are mostly small and occur in bleached arkosic sandstone and in carbonaceous shale lenses in close association with fossil plant debris, iron and copper sulfides, and copper carbonates. They have yielded only a few hundred tons of uranium ore, all from rocks of Permian and Triassic age. Deposits of this type also occur in steeply dipping beds of carbonaceous shale and sandstone of the Sangre de Cristo Formation, of Pennsylvanian and Permian age, in the Coyote district, ALara County (Tschanz, Laub, and Fuller, 1958), but these deposits are low in grade and have been unproductive.

Three formations of Permian age contain scattered deposits, the Yates Formation in Eddy County, the Cutler Formation in Rio Arriba County, and the Abo Formation in Bernalillo, Sandoval, Sierra, and Torrance Counties. Some ore has been produced from the Hillfoot No. 1 (NW% sec. 8, T. 22 N., R. 3 E.), Red Head No. 2 (SW% sec. 8, T. 22 N., R. 3 E.) and Red Bird (NE1/1 sec. 8, T. 22 N., R. 3 E.) deposits in Rio Arriba County (locality 8, fig. 47), and from the Empire group (secs. 11-14, T. 10 S., R. 8 W.) and State mineral lease (possibly sec. 2, T. 12 S., R. 7 W.) in Sierra County (locality 17).

The Chinle Formation has yielded some ore from the Good Luck, Quay County (sec. 6, T. 7 N., R. 32 E., locality 18) (Griggs, 1955, pp. 192-194), and the Windy No. 9 (sec. 14, T. 17 N., R. 23 E., locality 20). Other scattered occurrences are found in San Miguel County in the Chinle (Baltz, 1955, pp. 36-39) or in other units of the Dockum Group; in the Salitral Shale Tongue, Agua Za.rca Sandstone Member, and Poleo Sandstone Lentil of the Chinle in Rio Arriba County (Wood and Northrop, 1946) ; in the Dockum Group in Socorro County ; and in the Shinarump (?) Member of the Chinle in Valencia County. These stratigraphic units are all of Triassic age.

Deposits in rocks of Jurassic age.—Rocks of Jurassic age contain the most important uranium deposits in New Mexico. Through 1963, they have yielded about 21 million tons or 99 percent of the ore, of which the Morrison Formation has yielded about 20 million tons (95 percent) and the Todilto Formation nearly 1 million tons (4 percent). The most important deposits are largely restricted to the southern margin of the San Juan Basin in the Ambrosia Lake (locality 5), Laguna (locality 6), Smith Lake (locality 4), and Gallup (locality 3) districts and, of less importance, the Shiprock (locality 1) and Chuska (locality 2) districts.

The lowermost deposits are in the Todilto Formation, which consists of a lower limestone unit 5 to 35 feet thick and an upper gypsum-anhydrite unit 0 to 75 feet thick. The deposits, generally nonvanadiferous, are in the limestone unit where it has been deformed by interformational folding and faulting. Some deposits are irregular in shape but most are elongate and range from 20 to 30 feet in width and from 100 to several thousand feet in length. Although most of the ore is in the lower part of the limestone, it may occur throughout the unit, and thus the ore bodies vary in thickness from a few feet to 20 feet or more. In a few places they extend into the top few feet of the underlying Entrada, Sandstone or a few feet into the overlying Summerville Formation. Most of the deposits that have been mined are in the Ambrosia Lake and Laguna districts (localities 5 and 6) where ore has been shipped from more than 40 properties (table 28). A few thousand tons have been mined from the Smith Lake district (locality 4; table 28) and a small amount has been produced from the Wasson deposit in Rio Arriba County (locality 7). Details on these deposits and their stratigraphic relations are given by Gabelman (1956a, pp. 387400), Hilpert, and Moench (1960, pp. 429-464), and McLaughlin (1963, p. 149).

The uranium-bearing Morrison Formation is distributed over the northern one-third of New Mexico and extends into adjoining States. It consists mostly of claystone or mudstone interbedded with thick lenses of sandstone, some of which are conglomeratic. In northwestern New Mexico the formation is divided into four members. The

lowest member, the Salt Wash, crops out only in the extreme northwestern corner of the State, where it contains vanadiferous uranium deposits. The other three members, the Recapture, West water Canyon, and Brushy Basin, named in ascending order, extend over most of northwestern New Mexico ; the upper two members contain the largest known uranium deposits in the State, those located between Gallup and Albuquerque. The Morrison Formation has not been subdivided in northeastern New Mexico. Details of the lithology, thickness, and areal distribution of the members of the Morrison in northwestern New Mexico are contained in Rapaport and others (1952), Smith (1954), Kelley and Wood (1946), Craig and others (1955), Freeman and Hilpert (1956), Strobell (1956), and Hilpert (1963).

The uranium deposits generally occur in thick gray sandstone beds where these beds contain relatively thin and discontinuous lenses of claystone and abundant carbonized plant debris or fine-grained carbonaceous material. The deposits are generally more or less elongate masses that occur in one or more layers and in belts or trends that are alined with the sedimentary structures of the enclosing host rocks. In the Gallup (locality 3), Smith Lake (locality 4), and Ambrosia Lake (locality 5) districts, the principal deposits are in the Westwater Canyon Member and some are in the overlying Brushy Basin Member. In the Laguna district (locality 6), they are mainly in the Jackpile sandstone (of local usage) in the upper part of the Brushy Basin Member. The principal mines in these deposits are listed in table 29 (Hilpert and Moench, 1960; Granger and others, 1961; Soc. Econ. Geol., 1963). The uranium deposits in the Chuska district (locality 2) are mostly in the Recapture Member and those in the Shiprock district (locality 1) are in the Salt Wash Member (table 29). Only the ores in the Salt Wash contain enough vanadium to be mined for this metal alone or as a coproduct with uranium; they have a U :V ratio of about 1 :10.

Outside the six principal districts (localities 1 to 6, inclusive), scattered deposits occur in the Morrison Formation, but they are mostly small; these occurrences include the Westwater Canyon Member in Sandoval County (locality 8; table 29) ; a sandstone unit at the top of the Brushy Basin Member in Rio Arriba County; unnamed sandstone beds in northwestern Quay County (Griggs, 1955, pp. 192, 195) ; and one in Harding County (locality 19). A few hundred tons of ore have been mined from the deposits in Sandoval and Harding Counties.

Deposits in rocks of Cretaceous age.—Deposits in rocks of Cretaceous age are generally small and low grade and consist of impregnations of yellow uranium minerals and dark-colored unidentified minerals finely disseminated in carbonaceous sandstone, uraniferous carbonaceous shale, and impure coal (Gabelman, 1956b, 303-319). The most important deposits are in the Dakota Sandstone, from which four properties in the Gallup district (locality 3), five properties in the Ambrosia Lake district (locality 5), and one property in Sandoval County (locality 8) have yielded about 60,000 tons of ore (table 30). The only other productive deposit is the Midnight No. 2 (NW$^1/_4$ sec. 12, T. 2 N., R. 11 W.) in the Point Lookout Sandstone in Catron County (locality 11), from which some ore has been mined. Other deposits occur, mostly in the Mesaverde Group, in Catron (locality 11), McKinley (locality 5), Sandoval (locality 8), north-central and

southwestern San Juan, and western Socorro Counties. Of these, the largest is contained in the La Ventana Tongue of the Cliff House Sandstone at La Ventana Mesa (locality 8), Sandoval County. Here the uranium is in a zone several feet thick that includes three beds : an upper bed, 6 inches to 6 feet thick, of gray sandstone; a middle bed, 2 inches to 4 feet thick, of coal and impure coal; and a lower bed, as much as 10 feet thick, of carbonaceous shale. The middle bed contains the highest grade material (Bachman and others, 1959).

Deposits in rocks of 7'ertiary and Quaternary(?) age.—Deposits in rocks of Tertiary and Quaternary (?) age are also generally small and low grade. They consist mostly of coatings of carnotite, tyuyamunite, schrockingerite, and meta-autunite in iron-stained carbonaceous sandstone and siltstone. They occur mostly in Catron (locality 11) and northwestern Socorro Counties in the Eocene (?) Baca Formation; in Rio Arriba County along the eastern side of the San Juan Basin in the Paleocene Nacimiento and Eocene San Jose Formations; in eastern Rio Arriba County in the Miocene, Pliocene, and Pleistocene(?) Santa Fe Group; in northeastern San Juan County in the San Jose Formation; in southeastern Sandoval County in the Eocene and Oligocene(?) Galisteo Formation ; and in northern Santa Fe County in the Santa Fe Group and in the southern part of the County in the Galisteo Formation. Ore has been mined only from the Red Basin No. 1 (NE% sec. 19, T. 2 N., R. 10 W.), which is in a carbonaceous sandstone lens at the base of the Baca Formation (Bachman and others, 1957, pp. 11-12), Catron County (locality 11).

VEIN DEPOSITS

Uranium in vein deposits in New Mexico occurs in a wide variety of rock types and structures. These are not an important source of uranium, having yielded only about 15,000 tons of ore through 1963. The ore has come mostly from fault-controlled deposits in sedimentary rocks along the Rio Grande structural trough in Socorro County (localities 12 and 16), and from fissure veins in La Bajada area. Santa Fe County (locality 9), and Grant County (locality 14). Small amounts have been yielded by deposits in brecciated sedimentary and volcanic rocks from Catron (locality 10), Sierra (locality 13), and Hidalgo (locality 15) Counties, and from pegmatites in San Miguel County (locality 21). The vein deposits are summarized by county in table 31.

TABLE 31.—*Uraniferous vein deposits and occurrences in New Mexico.*

Name	Location (section, township, and range, New Mexico Principal Meridian)	Geology	References
Bernalillo County:			
Cerro Colorado-Archuleta	1, 9 N., 1 W. (projected; unsurveyed land).	Yellow uranium minerals in fractures in Tertiary rhyolite dome.	Wright, 1943, pp. 43–46; writer's field notes.
Catron County:			
Baby	20, 10 S., 19 W. (locality 10, fig. 47)	Mineralized fault in Tertiary andesite agglomerate	A. P. Butler, Jr., written communication, September 1964.
Colfax County:			
Blasted Pine	1, 27 N., 25 E.	Radioactive vein or fracture in Dakota Sandstone near Tertiary intrusive.	A. P. Butler, Jr., oral communication, September 1964.
Dona Ana County:			
Blue Star	13, 24, 25, 24 S., 3 E. (locality 22, fig. 47).	Uraniferous fluorite in faulted limestone and shale of Magdalena Group.	A. P. Butler, Jr., written communication, September 1964.
Grant County:			
Floyd Collins (probably same as Merry Widow).	21–22, 20 S., 15 W. (locality 14, fig. 47)	Autunite and torbernite occur in quartz-pyrite veins that cut Precambrian granite.	Lovering, 1956; A. P. Butler, Jr., written communication, September 1964.
Inez (7-X-V Ranch)	34, 20 S., 15 W. (locality 14, fig. 47)	Similar to Floyd Collins (above)	A. P. Butler, Jr., written communication, September 1964.
Hines No. 1	34, 21 S., 14 W.	Uraniferous fluorite and autunite(?) in quartzite breccia in shatter zone in Cambrian and Ordovician Bliss(?) Sandstone.	Lovering, 1956, pp. 352–353.
Langford	25, 22 S., 16 W.	Yellow uranium mineral and uraniferous fluorite in silicified breccia zone in Precambrian granite.	Lovering, 1956, pp. 353–354.
Black Hawk district	21, 18 S., 16 W.	Pitchblende occurs in fissure veins in association with various nickel, cobalt, and silver minerals. The veins are principally in the Black Hawk, Good Hope, and Alhambra mines along the southeast side of the Tertiary Twin Peaks monzonite stock.	Gillerman and Whitebread, 1956.
Hidalgo County:			
Napane	25, 29 S., 14 W. (locality 15, fig. 47)	Silicified zone (vein?) in Cretaceous limestone	A. P. Butler, Jr., written communication, September 1964.
Lincoln County:			
Prince	14, 6 S., 11 E.	A pyrometasomatic magnetite-hematite replacement of limestone in the Permian Yeso Formation at the margin of the Lone Mountain monzonite stock. The uranium is in unidentified minute particles in the magnetite and in secondary coating in fracture and pore spaces.	Walker and Osterwald, 1956, pp. 213–222.
Silverton	22, 8 S., 15 E.	Radioactive brecciated fault zone in Tertiary monzonite	A. P. Butler, Jr., written communication, September 1964.
Luna County:			
Cooks Peak area	12–13(?), 20 S., 9 W.	Uranium-bearing fluorite in vein cutting Carboniferous limestone.	Do.
Name unknown	12, 29 S., 11 W.	Autunite(?) with iron and copper sulfide in brecciated, silicified, Carboniferous limestone.	Do.

Rio Arriba County:			
Beryl (may be same as the Lonesome deposit).	Possibly NE¼ 1, 26 N., 8 E., or SW¼ 36, 27 N., 8 E.	Samarskite, uraninite, gummite, and monazite occur sparsely with columbite-tantalates in a microcline-quartz pegmatite body.	Just, 1937, p. 67; Jahns, 1946, pp. 137–142.
Pino Verde	NW ¼ 18, 26 N., 9 E.	A microcline-quartz pegmatite dike that contains sparse columbite, samarskite, monazite, and uraninite.	Jahns, 1946, pp. 183–185.
Kiawa	11, 27 N., 8 E.	Samarskite, magnetite, and bismutite occur in fractures in massive quartz in a microcline-quartz pegmatite dike.	Jahns, 1946, pp. 106–115.
North Star	31, 27 N., 9 E.	Similar to Pino Verde (above)	Jahns, 1946, pp. 144–146.
Tusas & JOL	24, 28 N., 7 E., and 18, 28 N., 9 E. (uncertain).	Autunite, torbernite, and sabugalite sparsely disseminated in Precambrian Petaca Schist along walls of purple fluorite veins.	Anonymous file data, probably from AEC.
Sandoval County:			
Mimi No. 4	4, 12 N., 6 E.	Autunite occurs along fractures near base of trachyte sill that intrudes the Mesaverde Group.	G. E. Collins, written communication, May 1955.
Peralta Canyon	9, 17 N., 5 E. (projected; unsurveyed land).	Torbernite and uranophane, associated with copper oxides, coat fracture surfaces and fill open space of brecciated rhyolite.	Jones, 1904, p. 342; Lindgren, Graton, and Gordon, 1910, p. 162.
Santa Fe County:			
La Bajada	9, 15 N., 7 E. (projected, unsurveyed land) (locality 9, fig. 47).	A complex deposit of various metallic sulfides along the brecciated footwall of a limburgite dike in the Tertiary Espinaso of Stearns (1943). Uranium (in unidentified minerals) is disseminated in podlike zones with the sulfides.	Writer's field notes and J. W. Hasler, written communication, October 1955.
Sierra County:			
Pitchblende Strike	26, 10 S., 6 W. (locality 13, fig. 47)	Uraninite and uranophane in brecciated body of chert and limestone (Madera Limestone) enclosed in Tertiary andesite.	Everhart, 1956b, p. 99; A. P. Butler, Jr., written communication, September 1964.
Socorro County:			
Charley No. 2 (Jeter)	35, 3 N., 2 W. (locality 16, fig. 47)	Carnotite, tyuyamunite, autunite, and pitchblende are disseminated in a roughly tabular zone of clayey material and bleached tuffaceous sandstone along the base of the Popotosa Formation where it is in fault contact with underlying Precambrian granite.	Writer's field notes and miscellaneous AEC file data.
Shaft	10, 1 S., 2 W.	Torbernite(?) and carnotite(?) associated with copper carbonates in shear zone in trachyandesite of Tertiary Datil Formation.	Gott and Erickson, 1952, pp. 4 and 13.
Agua Torres	1, 1 S., 2 E. (locality 12, fig. 47)	Fracture fillings of yellow uranium mineral in siliceous limestone breccia on west side of fault that separates the Madera and Abo Formations.	AEC file data.
Marie	12 and 13, 1 S., 2 E. (locality 12, fig. 47)	Similar to Agua Torres (above)	Do.
Carter-Tolliver-Cook	5 and 6, 2 S., 1 W.	Carnotite and uranophane, associated with iron, lead, and copper sulfides occur in mafic dikes that crosscut Precambrian granite and metamorphic rock.	Anonymous file data.
Lucky Don	35, 2 S., 2 E. (locality 12, fig. 47)	Tabular deposit of disseminated carnotite and tyuyamunite in San Andres Limestone in footwall of a fault that separates the Permian San Andres and Yeso Formations.	Writer's field notes.
Little Davie	35, 2 S., 2 E. (locality 12, fig. 47)	Deposit immediately south of, and similar to, Lucky Don (above).	Do.

TABLE 31.—*Uraniferous vein deposits and occurrences in New Mexico*—Continued

Name	Location (section, township, and range, New Mexico Principal Meridian)	Geology	References
Valencia County:			
Woodrow	36, 11 N., 5 W. (locality 6, fig. 47)	Coffinite and other uranium minerals, pyrite, and marcasite impregnate breccia in periphery of a vertical pipe structure in Morrison Formation.	Hilpert and Moench, 1960; Wylie, 1963, pp. 177–181.

RESOURCES

As of January 1, 1963, the U.S. Atomic Energy Commission estimated the uranium reserves in New Mexico to be 32.5 million tons of ore averaging about 0.25 percent U_3O_8 and containing 79,000 tons of U_3O_8.[1] Although more than 2 million tons of ore were mined in 1963, the reserve remained about the same in early 1964 as a result of mine development. This reserve is roughly one-half of the U.S. total ore reserves and enough to sustain a mine yield for 10 to 15 years at the 1963 rate of extraction.

New Mexico's reserves are almost entirely in relatively thick sandstone units in the Westwater Canyon and Brushy Basin Members of the Morrison Formation in the Ambrosia Lake and Laguna districts, McKinley and Valencia Counties. Relatively small reserves are contained in the Todilto Limestone and Dakota Sandstone in these same districts and the remainder is scattered throughout various formations in other parts of the State.

In addition to these ore reserves, an appreciable tonnage of material of submarginal grade occurs on the peripheries of the known ore deposits, especially those in the Ambrosia Lake district. This material has not been thoroughly sampled, and its tonnage has not been calculated, but it probably amounts to several million tons of material averaging 0.1 percent U_3O_8 or a little less. This material cannot be recovered profitably under present economic conditions and may be recoverable only at high cost after the mines are closed.

In contained uranium this peripheral submarginal material may greatly exceed all other submarginal uranium resources in New Mexico, even though many low-grade or submarginal deposits are known in the State (see symbols for "occurrences" on fig. 47). Although an accurate appraisal cannot be made of these occurrences, because exploration and sampling of most of them has not been extensive, none appears to be large. One of the most promising of these is in La Ventana Mesa area, Sandoval County; Bachman and others (1959, p. 307) calculated it contains 132,000 tons of material, 1 foot or more thick, containing at least 0.1 percent uranium, and about 400,000 tons between 0.01 to 0.1 percent uranium.

Most of the potential resources probably occur in the southern San Juan Basin mineral belt.[2] This is a belt of favorable ground defined by numerous sedimentary, structural, and other geologic features which indicate it extends from the vicinity of Gallup eastward to the vicinity of the Rio Grande Valley (Hilpert and Moench, 1959). It is about 80 miles long, roughly 20 to 25 miles wide, and includes the Gallup, Smith Lake, Ambrosia Lake, and Laguna districts. Most of the resources in this belt probably will be found in relatively thick sandstone beds in the Westwater Canyon and Brushy Basin Members of the Morrison Formation. The deposits will generally occur at depths of 1,000 feet or more below the surface, with the depths increasing northward from the outcrop toward the center of the San Juan Basin.

Undiscovered deposits also are likely to occur in the Todilto Limestone where the limestone has been contorted and broken. These

John A. Patterson, address before the National Western Mining Conference, Denver, Colo., Feb. 8, 1963.

[2] Referred to by Kelley and others (1963) as the Grants mineral belt.

deposits may be expected to be small, however, and will occur several hundred feet stratigraphically below the Morrison deposits. Deposits also may occur in the Dakota Sandstone. These also are not likely to be large, but as they occur stratigraphically above the Morrison they may be found and exploited together with the deeper Morrison deposits.

In addition to the potential resources in the southern San Juan mineral belt, a fair potential exists in the eastern parts of the Shiprock and Chuska districts. In the Shiprock district the known deposits are in the Salt Wash Member of the Morrison where this member is relatively thick. The thick part apparently extends eastward into the San Juan Basin, as shown by thickness data and dip directions of sedimentary structures (Craig and others, 1955, figs. 21 and 26). Deposits are expected to occur, therefore, along this eastward projection. They will be found at depths of several hundred feet or more beneath the surface. In the Chuska district, the known deposits occur in the Recapture Member of the Morrison where the member crops out and also is relatively thick (Craig and others, 1955, fig. 22). The sedimentary structures here also indicate an eastward trend (L. C. Craig, written communication, 1962) and, along with the relatively thick sandstone, suggest an eastward projection of favorable ground. The undiscovered deposits in this ground also will occur at depths of several hundred feet, or more.

Other potential resources in New Mexico are expected to be relatively small and mostly unimportant from the standpoint of the uranium industry. Many deposits are likely present in sedimentary rocks of Permian, Triassic, and Tertiary ages. Most of them, however, are expected to be small because of the relative thinness of the sandstone and lack of carbonaceous debris in the units. The most favorable units appear to be the Cutler Formation of Permian age, the Agua Zarca Sandstone Member and Poleo Sandstone Lentil, both of Triassic age, along the eastern margin of the San Juan Basin, and the relatively thick sandstone units at the base of the Tertiary Baca Formation, in C'atron and Socorro Counties.

The potential for uranium in vein deposits is small. The best potential is probably for deposits in sedimentary rocks associated with faults along the Rio Grande Trough, and in complex fissure veins that contain assemblages of other metals in the White Signal, Black Hawk, and Los Cerrillos districts in Grant, Sierra, and Santa Fe Counties, respectively. Some of these deposits may prove to be profitable as small operations, although their output is not expected to constitute an important part of New Mexico's uranium industry.

VANADIUM

(By R. P. Fischer, U.S. Geological Survey, Denver, Colo.)

The consumption of vanadium in the United States has been increasing gradually, according to figures published by the U.S. Bureau of Mines. Consumption was about 2,000 short tons each year in 1960 and 1961, about 2,300 tons. in 1962, and about 2,900 tons in 1963. Of these totals, 75 to 80 percent have gone into special engineering, strudtural, and tool steels, where it is used as an alloy to control

grain size, impart toughness, and inhibit fatigue. The other principal domestic uses have been in nonferrous alloys and chemicals.

The bulk of domestic supplies, and nearly half of the world supply, has come from vanadium-uranium deposits in sandstone in southwestern Colorado and the adjoining parts of Utah, Arizona, and New Mexico. Other principal sources of vanadium include a deposit of vanadium-bearing asphaltite in Peru, vanadate minerals from the oxidized zones of some base-metal deposits in Africa, and vanadium-bearing iron deposits in Europe and Africa. These and similar iron deposits in many parts of the world contain very large resources of vanadium. Probably they will become increasingly important as sources of vanadium in the future.

Of these four principal types of commercial vanadium deposits, only two are known in New Mexico, vanadium-uranium deposits in sandstone and vanadate deposits with base metals. Each type has yielded a small amount of vanadium, but the exact amount has not been reported in publication. Known occurrences of these types are shown on figure 47, which also shows uranium occurrences in New Mexico.

Uranium deposits in sandstone are numerous in northwestern New Mexico (fig. 47), and some of those in McKinley and Valencia Counties are large, yielding important amounts of uranium ore. The average vanadium content of most of these deposits, however, is only a few tenths of 1 percent V_2O_5 or less, which is too low to make its recovery profitable, although a little vanadium has been recovered in processing some uranium concentrates. One group of deposits (No. 1, fig. 47) along the Arizona State line in northwestern San Juan County, on the other hand, yields ore containing more than 1 percent V_2O_5. During World War II these deposits were mined for vanadium alone, and since the late 1940's they have been mined for both vanadium and uranium. Ore production from these deposits, however, has been relatively small.

The total content of vanadium in the known sandstone-type deposits in New Mexico amounts to many thousands of tons. Because of the low vanadium content in most of these deposits, however, very little of this metal can be recovered profitably unless economic or technologic factors change to favor vanadium. The geology of these deposits is described in the section on uranium in this report.

Crystals of lead, zinc, and copper vanadates are common in the oxidized zones of base-metal deposits in areas of arid or semiarid climates in many parts of the world. Generally these crystals are irregularly scattered in the oxidized zones, though in places they are concentrated in patches or bodies from which some material of commercial grade can be obtained by selective mining. In Southwestern United States, vanadate minerals occur in many deposits but only a few of these have yielded commercial vanadium ore.

Vanadate minerals have been reported in at least 14 mining districts in New Mexico (fig. 47), but production has been reported only from locality a, the North Magdalena district (Lasky, 1932), Socorro County ; locality b, Hall mine, Hillsboro district (Lindgren and others, 1910; Anderson, 1957) and locality c, Caballo Mountains district (Hess, 1912; Lasky and Wootton, 1933; Kelley and Silver, 1952), Sierra County; and locality d, Lucky Bill mine, Central district

(Larsh, 1913; Lasky and Wootton, 1933; Lasky, 1936), Grant County. None of these are credited with a sustained vanadium output, however, so the yield is assumed to be small. Data for a quantitative resource appraisal are not available, but no significant production of vanadium is likely from any of the known deposits.

SELENIUM AND TELLURIUM

(By D. F. Davidson and H. C. Granger, U.S. Geological Survey, Denver, Colo.)

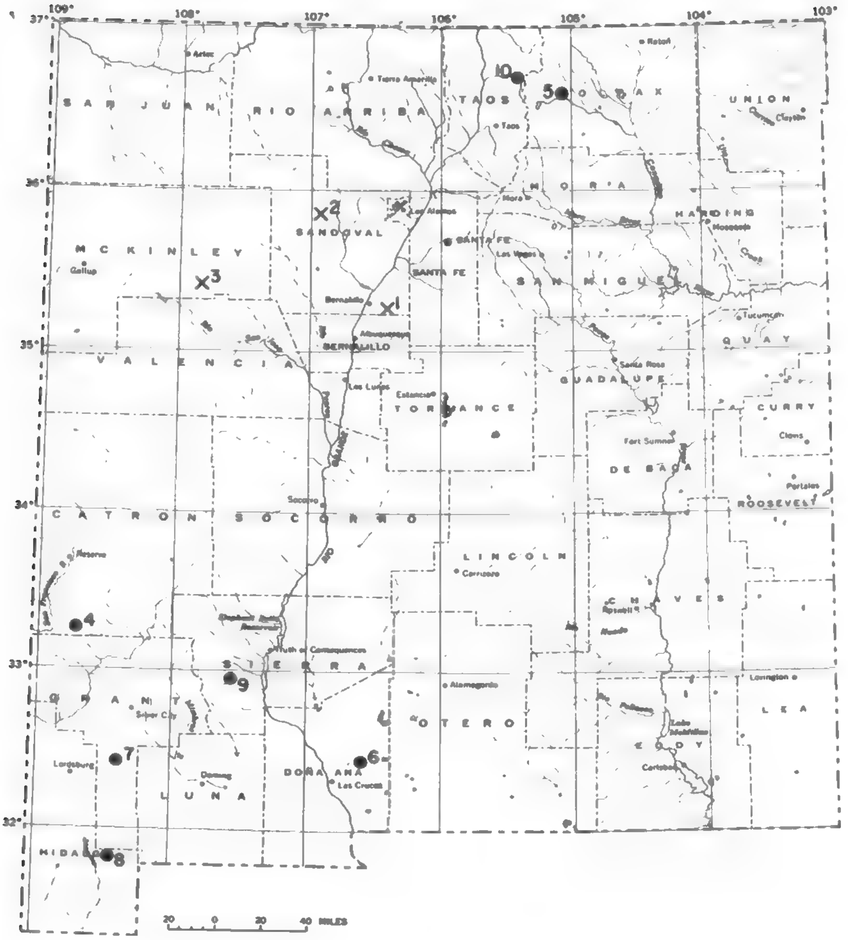
SELENIUM

Selenium is an allotropic element that is widely distributed in small quantities in the earth's crust. Where chemically pure, it may have the form of brick-red amorphous powder, a gray metallic crystalline mass, or red crystals. Selenium can act as either metal or nonmetal, electrical conductor or insulator, hydrogenator or dehydrogenator, colorant or decolorizer. It is toxic and is the only element that is often present in healthy plants in large enough quantities to be lethal to grazing animals.

High-purity selenium is used chiefly in electronic applications; commercial-grade selenium is consumed by the chemical, rubber, metallurgical, ceramic, and glass industries. Anode slime from electrolytic refining of copper is the principal commercial source of selenium, but lesser quantities are recovered from lead smelter flue dusts.

Most commonly, selenium is combined in sulfide or selenide minerals associated with copper, uranium, silver, antimony, and other metals; it occurs infrequently in the native state. No ores are mined exclusively for selenium. Selenium is known to occur in two principal kinds of deposits in New Mexico : (1) with uranium in sandstone deposits in the Ambrosia Lake or Grants district, Valencia County, and (2) in very low concentrations with uraniferous coal or coaly materials in the Hagen and La Ventana district, Sandoval County (fig. 48).

The selenium that occurs with the uranium ores being mined in the Grants uranium district may represent a future source of the element. The iron diselenide mineral, ferroselite, and gray native selenium have been identified but much of the selenium may occur in forms not yet recognized. Typical uranium ores from the Grants district contain 10 to 50 parts per million selenium. Local concentrations, particularly at the interface between oxidized and unoxidized host rock, may contain from several hundred parts per million to several tenths of a percent selenium. Because many million tons of uranium ore will be mined from the Grants uranium district by 1970 several hundred tons of selenium will have passed through the uranium mills. It has been generally conceded, however, that the overall grade of the selenium is too low to recover economically, and large-scale mining of the uranium does not permit selective mining of the selenium concentrations. Because of tendency of the selenium to move under oxidizing conditions and to be reconcentrated under reducing conditions in the vicinity of the ore deposits, it is possible that parts of the tailings piles from the uranium mills may become selenium ore deposits after long exposure to weathering.



EXPLANATION

×

Selenium occurrences
1. Hagan district
2. La Ventana district
3. Ambrosia Lake district

●

Tellurium occurrences
4. Wilcox district
5. Ute Creek district
6. Organ district
7. Little Burro Mountain district
8. Sylvanite district
9. Hillsboro district
10. Red River district

FIGURE 48.—Selenium and tellurium in New Mexico.

TELLURIUM

Tellurium is a toxic tin-white element that resembles antimony in appearance and is related to sulfur and selenium. It is neither as widespread nor as often concentrated as sulfur or selenium. It occurs in the native state and in more than 40 minerals, none of which is processed solely for the element. The tellurium of commerce is recovered as a byproduct during the refining of copper and lead ores. Only small quantities of tellurium are required for most of its applications in the ceramic, chemical, metallurgical, and rubber industries; it has been substituted satisfactorily for selenium in some applications when that element was in short supply. The future of tellurium is uncertain. It is potentially useful in thermoelements which convert heat froth solar energy or other sources to electricity, and may become increasingly important in space travel.

Tellurium has been found in at least seven mining district in New Mexico, associated with gold deposits (fig. 48). Tellurium or tellurium minerals have been described from the Wilcox district, Catron County ; Ute Creek, Colfax County; Organ district, Dona Ana County; Little Bruno Mountain, Grant County ; Sylvanite, Hidalgo County ; Hillsboro, Sierra County ; and Red River Taos County. Only one occurrence, at the Lone Pine mine, Wilcox district, has been explored as a possible source of tellurium ; there, at least 5 tons of high-grade tellurium "ore" have been produced since the early 1930's.

THORIUM

(By M. H. Staatz, U.S. Geological Survey, Denver, Colo.)

Thorium is a silver-gray metal that, like uranium, is the parent of a series of radioactive decay products ending in a stable isotope of lead. Because of this characteristic, thorium is a potential source of atomic power. Thorium, however, unlike uranium, does not contain a fissionable isotope to start the reaction. The uranium isotope 11_{235}, the only naturally occurring fissionable material, must be added. Once the reaction has begun, neutrons resulting from the U_{235} fissions will convert the thorium into U_{233} (Kelly, 1962, pp. 24-25). The use of thorium for nuclear energy is in the experimental stage and is in competition with relatively cheap and abundant uranium. By 1961, the U.S. Atomic Energy Commission had built or committed for construction five different types of reactors to study the use of thorium as a nuclear fuel (Baker and Tucker, 1962, p. 1211). The first commercial nuclear plant to use thorium as a fuel became operative in August of 1962 (Parker, 1963, p. 1199). Thorium also has a number of industrial uses. Over 90 percent of the thorium used in the United States goes into gas mantles and thorium-magnesium alloys. Minor amounts of thorium are also used in refractories, polishing compounds, chemicals, drugs, and electronic products. Experimental work has been carried out on thorium-nickel alloys.

Thorium occurs in a large number of minerals, but only a few of these have been found in sufficient concentrations to be used as ores. In many minerals it is associated with the rare earth elements. The most important source mineral for thorium in the world is monazite,

a phosphate of the cerium group rare earths. The thorium content of this mineral is variable, but commercial monazite contains between 3 to 10 percent thorium oxide (ThO_2) and 55 to 60 percent combined rare earth oxides (Kelly, 1962, p. 5). Monazite is found in pegmatites, granites, syenites, carbonatites, veins, metamorphic rocks, and in recent and fossil placers. Other potential sources of thorium are the minerals thorite and thorogummite, and multiple-oxide minerals such as euxenite, samarskite, and fergusonite. Thorite and thorogummite are found in veins and pegmatites. The multiple-oxide minerals occur in pegmatites and in placers derived from pegmatites.

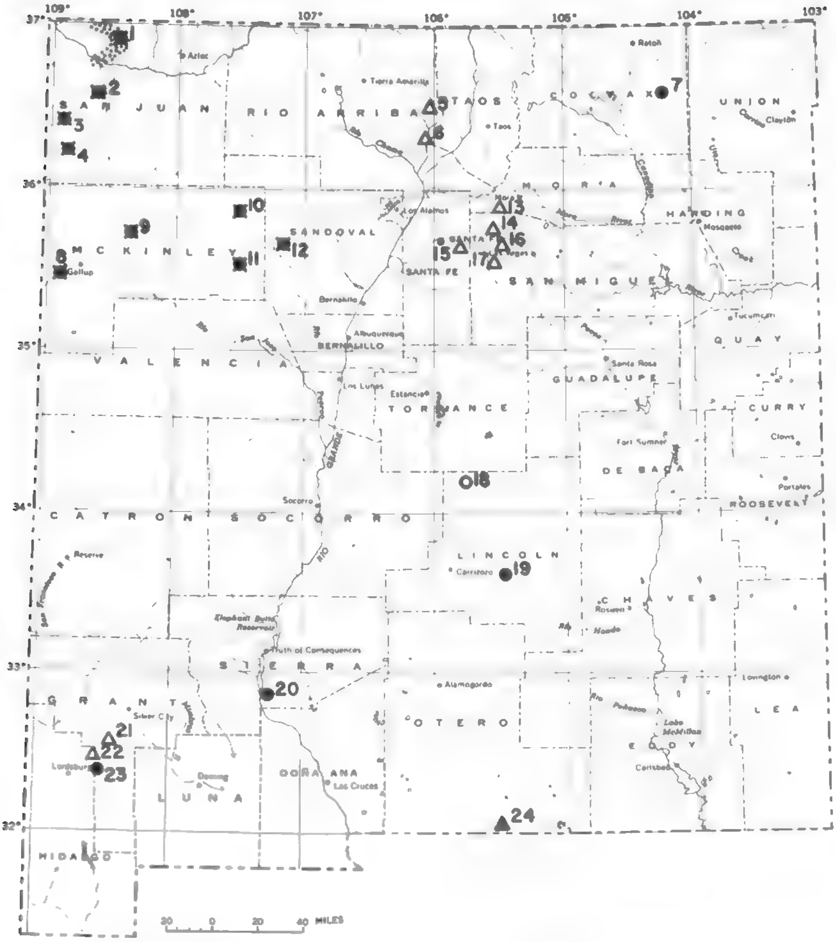
The present thorium requirements of the United States are small compared to many other metals. In 1961 only 121 tons of ThO_2 were used in this country (Baker and Tucker, 1962, p. 1210). Most of the ThO_2 used in the United States in 1962 was derived from Canadian uranium sludges and from South Africa's Vanrhynsdorp monazite lode (Parker, 1963, p. 1200). Some monazite has also come in recent years from placer deposits in North Carolina, Florida, and Idaho.

Although thorium deposits are known in a number of places in New Mexico, to date no thorium has been produced. The known New Mexico deposits are either smaller or of lower grade than similar deposits in other States. Furthermore, the marketing of thorium ores is difficult throughout the United States because there is no established market comparable to those for the more widely used metals and the prices of the ores are generally determined by negotiation between buyer and seller. Detailed information on economic factors bearing upon thorium, is given in a recent publication by the U.S. Bureau of Mines (Kelly, 1962).

In New Mexico thorium has been found in veins, pegmatites, and fossil and recent placers. Thorium-bearing veins are found in four parts of the State (Nos. 7, 19, 20, and 23, fig. 49). The most northern of these is in the Chico Hills (No. 7), where at least seven veins ranging from a fraction of an inch to 15 feet in width have been found m irregularly brecciated zones in Dakota sandstone and in phonolite. Their exposed length is from 10 to 550 feet. Vein material consists principally of quartz, iron-oxide minerals, thorite, plumbogummite, and brockite; brockite is the principal thorium mineral. A number of the veins averages 0.3 percent thorium oxide.

The second locality occurs in the Capitan Mountains (No. 19), where a number of irregular veins, similar to those in the Chico Hills, occur in brecciated fine-grained granite. Their thickness is extremely irregular, ranging from less than an inch to 8 feet. Most can be traced for distances of less than 100 feet. Thorite is the principal thorium mineral. Grade is highly irregular and may vary from a few hundredths to several percent thorium oxide within a few feet along the vein.

The third locality is at the southern end of the Caballos Mountains (No. 20), where scattered veins of orangish-red feldspar which cut granite of Precambrian age contain thorite, iron-oxide minerals, and rutile. A yellow uranium mineral and the rare earth mineral, bastnaesite, are also found in one of the veins. These veins are from a few inches to several feet wide and as much as several hundred feet long. Thorium content is erratic and some veins contain only a few hundredths of a percent of thorium oxide ; others as much as 0.5 percent.



EXPLANATION

Fossil beach placer

Fossil beach placer district covering broad area

Granitic pegmatite or group of pegmatites

Alkalic pegmatites

Veins containing thorium

Veins containing rare earths

DEPOSITS

1. Shiprock group
2. Chaco River
3. Sanostee
4. Toadlena
5. Petaca district
6. Ojo Caliente district
7. Chico Hills
8. Defiance
9. Standing Rock
10. Star Lake
11. Miguel Creek dome
12. Arroyo Torreon area
13. Pidlite pegmatite
14. Elk Mountain district
15. Dalton Creek
16. Sparks-Stone pegmatite
17. Bull Creek
18. Gallinas Mountains district
19. Capitan Mountains
20. Caballo Mountains
21. High Noon pegmatite
22. Gold Hill district
23. Grandview
24. Wind Mountain

FIGURE 49.—Thorium and rare earths in New Mexico.

The fourth locality is near the Gold Hill area (No. 23), where two small areas in a basalt dike have been weakly mineralized. These two areas have small veins containing thorite. Grade of this rock is less than 0.1 percent thorium oxide.

Pegmatites containing thorium minerals are found in the north-central and southwestern parts of New Mexico (fig. 49) . Thorium has been reported in these areas in one or more of the following minerals : monazite, samarskite, euxenite, fergusonite, and allanite (Olson and Adams, 1962; Jahns, 1946; Jahns, 1953, p. 1090; Northrop, 1944, p. 220; Anderson, 1957, p. 119). Monazite and samarskite are the most common. The thorium minerals are generally erratically scattered through a narrow zone in the pegmatite and are too sparse to serve as a source of thorium, although crystals of monazite and samarskite from the Petaca district (No. 5) have been sold to museums.

Recent placers are the principal source of thorium minerals in most regions; however, in New Mexico only trace amounts of thorium minerals have been found in such deposits. Thirty-five fossil placers, mainly sandstones, contain monazite in northwestern New Mexico (fig. 49). Twenty-seven of these fossil deposits are found in a zone northeast of Shiprock (No. 1). They represent consolidated beach sands containing various heavy minerals that were concentrated by waves and currents along an ancient beach (Dow and Batty, 1961, p. 3). All the deposits occur in sandstones of Late Cretaceous age. The fossil placers are lenticular or crescent shaped and generally not continuous. They range from about 50 to 7,300 feet long, 30 to 800 feet wide, and a half to 14 feet thick (Chenoweth, 1957, p. 213; Dow and Batty, 1961, pp. 34-40). Heavy minerals make up 50 to 60 percent of these sandstones and consist of ilmenite, leucoxene, zircon, and garnet, with minor amounts of monazite, rutile, spinel, epidote, magnetite, and tourmaline. New Mexico deposits contain an estimated 4,751,000 tons of titaniferous sandstone having a weighted average of 0.1 percent equivalent thorium oxide, 12.8 percent titanium oxide, 15.5 percent iron, and 2.1 percent zirconium oxide (Dow and Batty, 1961, p. 45). The greater part of these resources is concentrated in a deposit near Sanostee (No. 3), which is 7,300 feet long, 200 to 800 feet wide, and 1 to 14 feet thick. It has an average grade of 0.12 percent equivalent thorium oxide, or twice the grade of the next richest deposit (Dow and Batty, 1961, p. 40). A detailed description of this deposit is given by Bingler (1963).

Thorium deposits of New Mexico are not likely to be mined in the near future. In part this is due to the small demand for the element and to present competition from more cheaply mined foreign ores. In part this is also due to the small size and low grade of most of the known deposits. Present uses do not favor an increased demand in the immediate future, but the possibility of increased use of thorium as a source of power in atomic reactors or in some of the new special-use alloys now being developed suggest an increase in the not too distant future. Additional uses will depend on advances in technology, which may result from current and projected research. The largest tonnage of thorium known in the State is in the fossil placer deposit near Sanostee. This placer is primarily a titanium property from which a thorium concentrate could be produced as a byproduct. The long distances to markets, however, do not favor operation of this placer in

the immediate future. The known vein deposits are too small and the thorium is too erratically distributed to compete in the near future with bigger and richer vein deposits in Idaho and Colorado.

Possible exploratory targets for thorium in New Mexico include veins that are larger and higher in grade than those now known. Vein deposits are commonly found near alkalic rocks, such as syenite and phonolite, and areas surrounding this type of rock, as in the Gallinas Mountains in Lincoln County or in the Cornudas Mountains in Otero County, should be examined first. Further exploration for larger deposits might also be carried out in the Chico Hills (No. 7) and the Capitan Mountains (No. 19).

RARE EARTHS

(By J. W. Adams, U.S. Geological Survey, Denver, Colo.)

The rare earth metals comprise the 15 elements having atomic Nos. 57 to 71, including lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). One of these, promethium, is not known to occur in nature. Yttrium (Y), with atomic No. 39, is also classed with the rare earths because of its chemical similarities and geochemical affinities.

The first seven elements listed above (La through Eu) are included in the cerium group of rare earths, so-called because cerium is their most abundant member. The remaining eight elements (Gd through Lu) together with yttrium are called the yttrium group. The two groups are also referred to, respectively, as the "light" and "heavy" rare earths. The properties of the members of the two groups of rare earths are sufficiently distinct to cause one group to predominate over the other in most minerals where they occur, even though all or nearly all are ordinarily present (Olson and Adams, 1962).

The rare earths have many industrial applications such as in the steel industry, nonferrous alloys, glass manufacture and glass polishing, sparking alloys, and carbon electrodes for arc light and projection lamps. Rare earth requirements are, however, relatively small compared to many other metals; domestic consumption in 1958 being only about 1,600 short tons of rare earth oxides (Baroch, 1960, p. 687). The rare earth industry is developed almost entirely around the cerium group elements, primarily cerium, lanthanum, praseodymium, and neodymium. Although considerable research is being directed toward finding uses for yttrium and the heavy rare earth elements the current demand for them is small.

The rare earths are found in a large number of minerals, but only a few of these have been found in sufficient concentration to be used as ores. The most widely used source mineral is monazite, a rare earth phosphate, but deposits of bastnaesite, a rare earth fluorcarbonate, are found in fsTew Mexico. Bastnaesite is currently being mined at Mountain Pass, Calif. Both monazite and bastnaesite contain dominantly cerium group elements.

Commercial monazite commonly contains 55 to 60 percent combined rare earth oxides and between 3 to 10 percent thorium oxide (Kelly,

1962, p. 5). Monazite is not only the principal ore mineral of rare earths, but the principal one of thorium (see "Thorium" chapter) as well. Bastnaesite has a slightly higher rare earth content than does monazite, but contains little or no thorium.

Minerals in which the yttrium group elements predominate include xenotime, and yttrium phosphate, and euxenite, a multiple oxide of yttrium, niobium, and titanium.

The marketing of rare earth ores is difficult as there is no established market comparable to that of the more widely used metals, and prices are generally determined by negotiation between buyer and seller. Detailed information on the economics of rare earths is given in a recent publication of the U.S. Bureau of Mines (Kelly, 1962).

Rare-earth-bearing minerals have been found at a large number of localities in New Mexico (fig. 49) in several different geologic environments, including vein deposits, pegmatites, and ancient placers. The most important rare earth deposits are in the Gallinas Mountains in Lincoln County (No. 18), where bastnaesite occurs in fluorite- and fluorite-copper-bearing veins and breccia fillings. The rare earth mineral was discovered in 1943 during an investigation of the fluorspar potential of the district by the U.S. Bureau of Mines and the U.S. Geological Survey (Glass and Smalley, 1945; Soule, 1946), and although the deposits appear to be quite small, their rare earth potential is not known.

The deposits in which the bastnaesite occurs are largely confined to the Yeso sandstone and appear to be genetically related to younger alkalic rocks that are intrusive in the area (Perhac and Heinrich, 1964). The location of most of the deposits is shown on the geologic map of the area by Kelley (1947).

In the Gallinas district, bastnaesite occurs as small yellow crystals in vein material that is commonly rich in fluorite but which may contain barite, quartz, calcite, pyrite, copper sulfides, galena, and supergene minerals such as limonite. Very little thorium is present in the bastnaesite, and the radioactivity of the vein material is slight. The best known occurrence is at the Red Cloud mine, where a 1,400-pound sample of fluorspar ore from the Red Cloud mine contained 3.2 percent total rare earth oxides (Soule, 1946, p. 21), which would represent nearly 5 percent bastnaesite. Locally the bastnaesite may be much more abundant, and Soule (1946, p. 7) noted that in the Red Cloud mine it occurred well beyond the limits of the better grade florspar ore. Bastnaesite has been found in most of the fluorite and fluorite-copper deposits in the Gallinas area (Perhac and Heinrich, 1964, p. 231). The bastnaesite content of the various deposits has not been determined, but from modal analyses of high-grade specimens (Perhac and Heinrich, 1964, p. 231) it would appear that most of the veins contain less than 5 percent.

During the period 1954-56, approximately 71 tons of bastnaesite concentrate were produced, most of which came from the Red Cloud (Conqueror No. 9) mine (Griswold, 1959, p. 64). No further production of rare earth ores has been reported from the Gallinas district, probably because the limited market for bastnaesite is adequately supplied by the very large deposit at Mountain Pass, Calif.

Rare earths have been found in other vein-type deposits in New Mexico, notably those in the Chico Hills, Colfax County (No. 7) ; in the Capitan Mountains, Lincoln County (No. 19) ; and in the Caballo

Mountains, Sierra County (No. 20) where bastnaesite occurs in at least one radioactive deposit (see "Thorium" chapter).

Pegmatite is a type of igneous rock generally considered to represent the crystallization product of residual magmatic fluids (see "Pegmatite" chapter) and as such may contain concentrations of a number of rare elements whose properties inhibited their entry into the minerals of earlier formed rocks. The rare earths are among these elements and appear in pegmatites as the major constituent in a number of minerals as well as a minor constituent of several others.

Rare earth minerals occur in a large number of granitic pegmatites in New Mexico. Most of these deposits are in north-central New Mexico, chiefly in the Petaca and Ojo Caliente districts (Nos. 5 and 6) in Rio Arriba County (Jahns, 1946; Redmon, 1961) and along the east side of the Sangre de Cristo Mountains (Nos. 13, 14, 15, 16, and 17) in the southern part of Mora County and the northern part of San Miguel County (Jahns, 1946; Jahns, 1953; Redmon, 1961) . Rare-earth-bearing pegmatites are also found in the Gold Hill area (No. 22) in Hidalgo County, and in the White Signal district (No. 21) in Grant County.

Monazite is the most abundant rare earth mineral in the pegmatites of north-central New Mexico. It is commonly in small tabular tan to brick-red crystals, and is appreciably radioactive dile to contained thorium. Individual crystals and masses weighing as much as 10 pounds have been found in the Petaca district (Northrop, 1959, p. 359). In addition to monazite, several of the multiple-oxide-type rare earth minerals, such as samarskite, fergusonite, euxenite, and betafite have been reported (Northrop, 1959). Minerals of this group contain varying amounts of rare earth elements, together with niobium, tantalum, titanium, iron, thorium, and uranium ; are commonly dark brown to black ; have a glassy luster • and are highly radioactive. Identification of individual species is difficult and commonly requires X-ray analysis.

The beryllium-bearing rare earth silicate, gadolinite, has been noted by Jahns (1946, p. 285) in pegmatites in the Elk Mountain district (No. 14).

Pegmatites in the Gold Hill area in Hidalgo County (No. 22) are reported to contain the rare-earth-bearing silicate, allanite, as well as euxenite, samarskite, and cyrtolite, a variety of zircon in which the rare earths are important constituents. Euxenite has been found also in a pegmatite on the High Noon No. 1 claim in the White Signal district (No. 21) in Grant County (Olson and Adams, 1962).

There has been no significant production of rare earth minerals from granitic pegmatites in New Mexico, although some monazite has been recovered as a byproduct of mica mining in the Petaca and Elk Mountain districts (Jahns, 1946, p. 99; Redmon, 1961, p. 74).

Alkalic pegmatite dikes along the margin of the nepheline syenite laccolith of Wind Mountain in Otero County (No. 24) contain minor amounts of rare earths in the zirconium silicate, eudialite (Warner and others, 1959, pp. 137-138). Although this occurrence is in itself of little economic importance, the alkalic intrusive area of the Cornudas Mountains, of which Wind Mountain is a part, is a favorable environment for other rare earth deposits.

No important modern placer deposits of rare earth minerals have been reported in New Mexico, but there are many known occurrences

of ancient monazite-bearing placers in sandstones of Late Cretaceous age in northwestern New Mexico (Nos. 1, 2, 3, 4, 8, 9, 11, 12, and 16). These fossil placers represent accumulations of heavy minerals along the beaches of ancient regressive seas (Chenoweth, 1957, pp. 212-217), and, like modern beach deposits, they are narrow, lenticular sandstone bodies that follow the trend of the ancient shoreline. Some deposits, however, may be several thousand feet in length and several hundreds of feet in width and contain large tonnages of rock composed chiefly of quartz, feldspar, ilmenite, magnetite, leucoxene, zircon, and monazite cemented by ferric iron and carfonate minerals. The rock is characteristically dark in color and shows anomalous radioactivity, partly due to the thorium in the monazite. The fossil placer deposits have been explored chiefly for their titanium potential (Dow and Batty, 1961) and are estimated to contain nearly 5 million tons of rock with a weighted average of 0.10 percent equivalent thorium oxide.

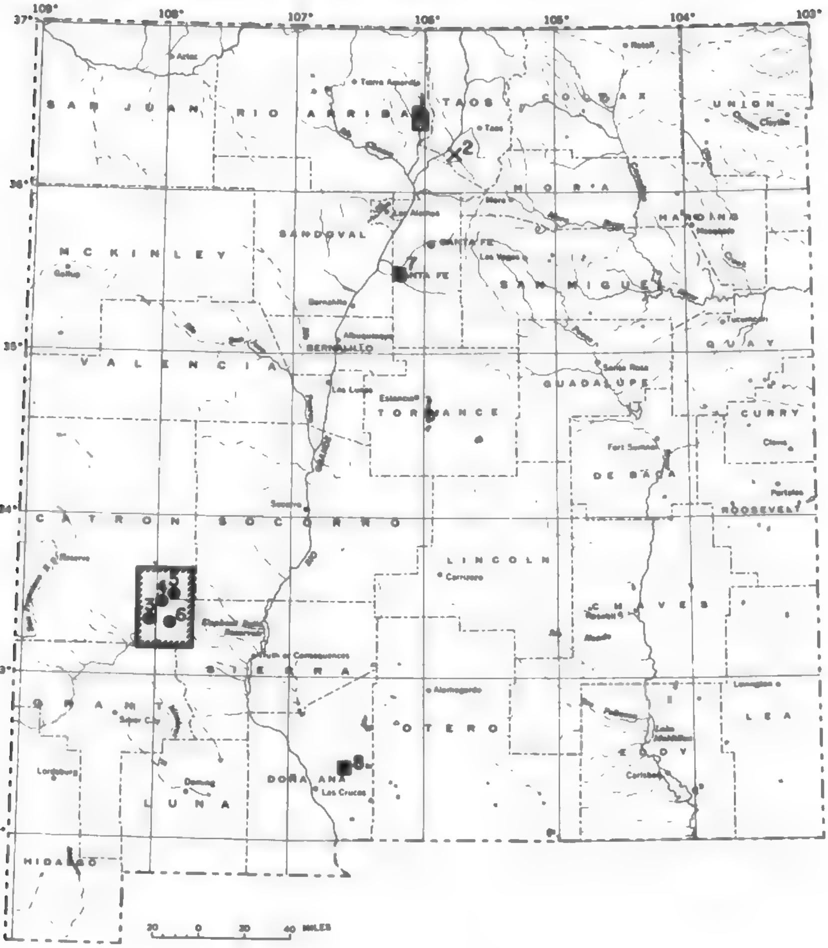
TIN

(By C. L. Sainsbury, U.S. Geological Survey, Denver, Colo., and **R.** H. Jahns, the Pennsylvania State University, University Park, Pa.)

Tin has been used by civilized peoples at least since the late bronze age (3500-3200 B.C.), and today it remains a strategic commodity of which the United States has little. The metal has two modifications: "white" tin of tetragonal symmetry and specific gravity 7.31, and "gray" tin of cubic symmetry and specific gravity 5.75 (Lange, 1961). At low temperatures (below 13.2° C.), the white tin changes to *gray* tin, which crumbles to a powdery mass. Alloying tin with any other metal prevents the change from white to gray tin. Toward air, water, and weak acids and bases, tin is chemically resistant because of the formation of a tin oxide coating. This inertness, along with its extremely low surface tension in the molten state, which allows it to build very thin coatings on other metals, leads to its main use as tinplate. Other major uses are as alloys in bearing metal and in solder, bronze, and brass.

Although the United States consumes more than 54,000 long tons of primary tin metal yearly (1962), it produces only a few tons, most of which comes from small tin deposits in Alaska and as a byproduct of molybdenum mining in Colorado. Of greater significance is the fact that total known U.S. resources of possible economic grade are but a small percentage of 1 year's consumption. Hence, every domestic tin deposit is of great interest, although this interest is tempered by the fact that tin has been easy to obtain on a worldwide basis, and, in fact, has often been in excess supply. The major tin-producing countries are Malaya, Indonesia, Bolivia, Republic of the Congo, and Nigeria, listed in decreasing importance.

In New Mexico, three different types of deposits that contain tin as a significant metallic constituent occur in well-defined areas, each of which includes more than one deposit. In spite of substantial exploration, however, no commercially important lode deposits have been found, and placer deposits have yielded concentrates equivalent to only a few tons of tin metal. Distribution of tin deposits in New Mexico is shown on figure 50.



EXPLANATION

×
Cassiterite in pegmatite
1. Petaca
2. Harding

●
Cassiterite in veins in rhyolite
3. Taylor Creek
4. Squaw Creek
5. Hardcastle Creek
6. Chloride

■
Tin sulfide deposits
7. Lone Star Mine
8. Merrimac Mine

Black Range district
Area of vein and placer deposits in rhyolite

Petaca district
Area of pegmatitic deposits

FIGURE 50.—Tin in New Mexico.

The Black Range tin district, mainly in Catron and Sierra Counties, is by far the most important in the State. It includes both lode and placer deposits that represent cassiterite-hematite-silica mineralization in rhyolite of Tertiary age (Fries, 1940). Best known are the Taylor Creek deposits, discovered in 1918 by J. N. Welch (Hill, 1921, p. 353), in the southwestern part of the district. Here cassiterite and specular hematite occur in small, discontinous veins. The cassiterite forms fracture fillings up to 1 inch thick, and also is disseminated in kaolinized and red-stained rhyolite that forms the walls of the veinlets. Some masses of altered rhyolite are of appreciable extent, but exploration of several of the best-exposed ones has indicated that the overall grade of a body of minable size generally does not exceed 0.02 to 0.06 percent of tin (Volin and others, 1947). Similar lode deposits have been worked on a small scale at more than a dozen other localities, notably in the Squaw Creek, Hardcastle Creek, and Scales Creek areas in the northern and eastern parts of the district. A few of them are locally rich in cassiterite, but all are very low in grade with respect to rock masses of minable extent.

Where streams have cut into the tin-bearing rhyolites, cassiterite has accumulated as placers. A few tens of tons of high-grade concentrates have beeen recovered from very coarse gravels, chiefly in the eastern part of the district, and from thin residual accumulations near the head of Squaw Creek, but none of the placer deposits contains more than a few thousand cubic yards of material with as much as 2 pounds of tin per cubic yard. Most of the placers contain less than 0.05 pound of tin per cubic yard (Fries, 1940, pp. 365-366).

Scattered lode deposits of cassiterite are present farther east in Sierra County between the Sierra Cuchillo and the western margin of the Rio Grande Valley. As in the Black Range district, they are associated with altered rhyolite of Tertiary age. The cassiterite occurs with specular hematite as fracture and vug-filling aggregate at numerous localities in a belt at least 15 miles long, but all the known deposits are either very small or very low in grade. No production has been recorded from any of them.

A second general type of tin deposit in New Mexico is represented by cassiterite and other tin-bearing minerals sparsely and sporadically scattered through pegmatite bodies. A few of the Precambrian mica-bearing pegmatites in the Petaca district, Rio Arriba County (Jahns, 1946), contain trace amounts of cassiterite and many more of them contain samarskite, columbite-tantalite, and other heavy accessory minerals in which some tin is present. A little tin also occurs in the pyrochlore and tantalite-columbite of the Harding pegmatites, Taos County, and in these or other accessory minerals in the Pidlite pegmatite, Mora County, the Pecos pegmatites, San Miguel County, and in several other Precambrian pegmatites of the Picuris-Sangre de Cristo region. Cassiterite and a little stannite are present locally in pegmatites and pegmatitic quartz monzonite of Tertiary age in the Organ Mountains, Dona Ana County. The tin-bearing minerals in all these pegmatite occurrences can be recovered along with other heavy minerals only as a byproduct of mining devoted to other commodities, and the total amount of tin contained in the known pegmatites is probably less than a ton.

Tin sulfide minerals, present mainly in vein deposits, constitute the third general type of occurrence. They have been identified

at the Lone Star and other mines in Santa Fe County, and at the Merrimac mine in Dona Ana County, where they are only of mineralogical significance.

The past history of extensive exploration for tin and the record of tin production from deposits in New Mexico provide little hope for finding deposits larger or richer than those now known. Future attempts to find deposits of commercial value might best be directed toward the rhyolites in the southwestern part of the State, and especially toward the zones of alteration within these rocks. Some large-tonnage, low-grade deposits now known in this region have not yet been fully evaluated, and similar deposits may well remain to be discovered.

TITANIUM

(By E. C. Bingler, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

The growing importance of titanium is demonstrated by its increasing use in various components of high-speed aircraft and space vehicles. The properties of titanium metal that have contributed to its increasing usefulness are high strength to weight ratio and chemical inertness. Titanium dioxide in the form of ilmenite and rutile is widely used in the paint industry to prepare white pigment. Domestic production of titanium dioxide concentrates is increasing, but no production has been recorded in New Mexico.

Titanium in cationic form occurs in the mineral rutile and its polymorphs, anatase and brookite. In anionic form, this element commonly occurs in ilmenite and sphene. Small amounts of titanium are often present in magnetite as exsolution lamellae or in solid solution. All these minerals, but especially rutile, ilmenite, and sphene, are common accessory minerals in igneous rocks, pegmatites, and ore deposits. Because of their high density and resistance to abrasion, the titanium minerals are often concentrated in alluvial deposits such as beach and river sands.

In New Mexico, titanium occurrences have been reported from pegmatites, iron ores, river sands, and Upper Cretaceous sandstones. Jahns (1946, p. 67) noted that ilmenite in the form of tabular crystals is common in quartz veins and quartz-rich pegmatites in the Petaca district, Rio Arriba County. Titanium in New Mexico iron ores has been reported by Kelley (1949, p. 227). A sample of ore from the Council Rock district in Socorro County assayed 59.4 percent iron and 10 percent titanium. Sidwell (1946) studied river sand, which was derived from the Capitan Mountain alaskite in Lincoln County, that contains an unusually high concentration of anatase. Provenance studies in the Middle Rio Grande Valley indicate that sand from Santa Fe Creek contains about 10 percent heavy minerals, of which 40 percent is ilmenite (Rittenhouse, 1944, p. 163).

Titaniferous sandstone lenses within the Mesaverde Group in the San Juan Basin contain the only known titanium occurrences of possible economic interest in New Mexico. These deposits are similar in mode of occurrence and mineralogy to deposits of Late Cretaceous age reported from Montana, Wyoming, Utah, and Colorado (Murphy and Houston, 1955 ; Dow and Batty, 1961). Chenoweth (1957)

described New Mexico deposits located by airborne radiometric surveys ; Sun and Allen (1957) described the mineralogy of a brookite-bearing deposit near Gallup, McKinley County ; Bingler (1963) described the mineralogy and stratigraphy of the largest known deposit, at Sanostee, San Juan County. According to Dow and Batty (1961, p. 45), New Mexico deposits contain an estimated 4,751,200 tons of titaniferous sandstone with an average titanium content of about 13 percent. Reliable estimates of tonnage are hampered, however, by the fact that many of the heavy mineral lenses are discontinuous and the degree of alteration which tends to increase the titanium content is highly variable among the deposits.

Titaniferous sandstones of Late Cretaceous age appear to offer the greatest economic potential. With increased demand and progress in titanium technology, some of these occurrences may become ore. Utilization of the deposits will be impeded, however, by lack of available water at the sites as well as considerable variation in the physical properties and mineralogic content of the lens material. The prospect for future utilization of these deposits would be enhanced by detailed study of known deposits, with emphasis on determination of size and grade.

TUNGSTEN

(By S. W. Hobbs, U.S. Geological Survey, Denver, Colo.)

Tungsten is a metal whose strategic value depends mainly on the unusual physical and mechanical properties of the element, its alloy, and certain special compounds. In pure form, tungsten is light gray, very heavy, and has the highest melting point of the metals (about 3,410° C., 6,170° F.). Tungsten alloys and carbides are notable for their extreme hardness and wear resistance, and particularly for retaining hardness at elevated temperatures.

Pure or nearly pure tungsten metal is important in electric lighting, electronics, and electrical contact applications. However, over 70 percent of domestic consumption is in alloy tool steel and tungsten carbide used for cutting edges, dies, drill bits, wear-resistant machine parts, and other applications where extreme hardness is desirable.

U.S. consumption in 1962 was 13,691,000 pounds of contained tungsten. Domestic mine shipments totaled 8,021,000 pounds, and imports for consumption were nearly 4 million pounds (U.S. Bureau of Mines Minerals Yearbook, 1962). Although the U.S. tungsten mining industry has operated continuously (except for 1921 and 1922) for over 50 years, the rate of production has ranged widely as a result of price fluctuations. Quotations for domestic tungsten in 1964 were $16 to $19 per short ton unit of WO_3, in contrast to a Government stockpile price of $63 in 1951-56 and a war-induced price of $85 in 1916. Output is quite sensitive to price, and at the low rates prevailing since 1956, few tungsten mines in the United States have been able to compete consistently on the open market with foreign producers (Holliday, 1960, p. 914). However, a large domestic productive capacity was demonstrated twice in the last two decades under conditions of special need or incentive : in 1943-45, to fill heavy demand of the war effort ; and between 1950 and 1956 under the influence of the price incentive of the Government stockpiling program during the Korean

crisis. In 1955, production reached an alltime peak that was nearly four times the average annual production of the immediate postwar period 1946-50. In 1956, nearly 600 operations reported some production; in 1958, after the removal of Government price support, only 2 producers were active (U.S. Bureau of Mines Minerals Yearbook, 1956, p. 1227, and 1958, p. 1091). These data illustrate dramatically the fact that the United States has a substantial supply of tungsten available if the need warrants the price that is necessary to extract it.

Tungsten minerals are widely distributed in various rock types of the earth's crust, but for the most part are genetically associated with igneous rocks of granitic composition. About 11 minerals contain tungsten as an essential component, but of these the only commercially important ones are those of the wolframite group, ferberite, $FeWO_4$, wolframite (Fe, Mn), WO_4, and huebnerite, $MnWO_4$, and scheelite, $CaWO_4$. Although the wolframite group is economically most important in the world as a whole, scheelite has accounted for nearly three-fourth of the U.S. output.

U.S. deposits include : quartz veins that contain minerals of the wolframite group, scheelite, or both; contact-metamorphic deposits containing scheelite in association with garnet and other silicates formed at places along contacts of granitic intrusive rocks with invaded limestone ; and disseminated hydrothermal deposits of scheelite and wolframite in igneous, sedimentary, and metamorphic rocks. Some tungsten-bearing minerals have also been found in pegmatites.

TABLE 32.—*Tungsten mines and prospects in New Mexico*

Map locality	County	District and mines	Manner of occurrence	Remarks	Selected references
1	Colfax	Elizabethtown	Minor ferberite in veins near the border of intrusive porphyry body.		Ray and Smith, 1941.
2	Taos	Picuris district: Copper Hill deposits.	Wolframite in malachite-stained quartz veins in Precambrian quartzite. Some tourmaline.	Reported very small production	Lesky and Wootten, 1933; Dale and McKinney, 1959.
3	San Miguel	El Porvenir district	Scheelite and ferberite in small amounts with molybdenite in quartz-rich pegmatite.		Lasky and Wootten, 1933.
4	Santa Fe	Cunningham Hill: Ortiz mine grant.	Scheelite in fractures of brecciated and fissured quartz monzonite stock and in sandstone. Associated with pyrite and minute amounts of gold.	Very large tonnage of low-grade material inferred for area. Estimates have been made of 10,000,000 or more tons containing between 0.025 and 0.075 percent WO_3.	Anderson, 1957; Dale and McKinney, 1959.
5	do	San Pedro group: San Francisco mine.	Small amounts of scheelite at places in tactite in old copper mine.		Anderson, 1957; Smith, Cooper, and others, 1945; Dale and McKinney, 1959.
6	Lincoln	White Oaks district: Little Mack property, and Hudspeth property.	Huebnerite in quartz veins and stringers in monzonite and Cretaceous sediments. Veins mined for auriferous pyrite in past. Tungsten in small shoots and pockets.	Production from 1915 to 1952 estimated at 3,000 units. Pockety nature of tungsten minerals precludes appraisal of potential.	Ellis, 1929; Lindgren, Graton and Gordon, 1910; Dale and McKinney, 1959; Griswold, 1959.
7	Socorro	Reinhart	Tungsten-bearing psilomelane veins in Tertiary agglomerate.	Mode of occurrence of tungsten in manganese minerals is not clearly understood.	Hewett and Fleischer, 1960.
8	do	Cliffside	Tungsten-bearing hollandite in Tertiary rhyolite.	do	Do.
9	do	Carretas	Tungsten-bearing coronadite in Tertiary rhyolite.	do	Do.
10	do	Magdalena district	Scheelite in silicified shear zones associated with lead and zinc sulfides.		Austin, 1960.
11	Sierra	Grandview Canyon prospect	Scheelite very erratically distributed in quartz veins and pods on or near contacts of granite with schist.		Lasky, 1932; Dale and McKinney, 1959.
12	Dona Ana	Merrimac mine	Scheelite in tactite that has been worked principally for zinc. Tungsten of [redacted] grade occurs in pockets but appears to be erratically distributed.	No recorded tungsten production	Dale and McKinney, 1959.
13	Sierra	Rockhouse	Tungsten-bearing psilomelane in veins in limestone.	Mode of occurrence of tungsten in manganese minerals is not clearly understood.	Hewett and Fleischer, 1960.
14	do	Manganese Hill	do	do	Do.
15	do	Jones-Reiland	do	do	Do.
16	Dona Ana	Velarde	Tungsten-bearing psilomelane vein in Tertiary rhyolite.	do	Do.

TABLE 32.—*Tungsten mines and prospects in New Mexico*—Continued

Map locality	County	District and mines	Manner of occurrence	Remarks	Selected references
17	Sierra-Socorro	Iron Mountain	Tungsten occurs as molybdenum-bearing scheelite in streaks and small disseminated masses in tactite that is comprised of garnet and magnetite and some helvite. Tactite zone is very extensive.	Individual tungsten deposits are reported to be small.	Jahns, 1944.
18	Sierra	Silver Queen group	Sparse scheelite in quartz bodies along fault zone between volcanic rocks and limestone.	Small amount of gold in vein. No tungsten production.	Dale and McKinney, 1959.
19	do	Berenda Creek prospects	Scheelite in quartz veins		
20	Grant	Central district	Tungsten in oxidized iron-manganese veins in a wide fault zone and as small replacement pods in limestone.	Mode of occurrence of tungsten in manganese minerals is not well known.	
21	do	Bullard Peak area: Morning Star claims, Zelma claims, Pacemaker claims, Greenrock claims, and Evening Star claims.	Scheelite in pegmatite and related quartz veins in gneiss and schist.	Scheelite very sporadic and pockety.	Do.
22	do	Rice-Graves deposit	Scheelite in silicified amphibolite inclusion in granite.		Do.
23	do	Bounds Ranch prospect: Hillside claims, Alpha claims, and Bluebird claims.	Scheelite and wolframite in narrow quartz veins. Some scheelite-bearing tactite.	Small shipment of ore in 1941	Do.
24	Luna	Victorio Mountains, Tedford's group.	Minor scheelite in tactite and some wolframite in quartz veins.		Do.
25	Hidalgo	Granite Gap: Sunrise prospect, Baker-Standard, and Scheelite group.	Scheelite erratically distributed in tactite	Small production reported	
26	Grant	Little Hatchet Mountains	Minor amount of scheelite in quartz-sulfide veins in metamorphosed sedimentary rocks.		Lasky, 1947.
27	Hidalgo	Apache	Some scheelite in copper-bearing tactite	No tungsten production	Lasky and Wootton, 1933; Dale and McKinney, 1959.
28	do	Eagle Point deposits	Scheelite in tactite on limestone-granite contact		Lasky, 1947; Dale and McKinney, 1959.
29	do	Hoggett manganese deposits	Tungsten in psilomelane ore in veins cutting rhyolite porphyry.	Mode of occurrence of tungsten in manganese ores not fully understood. Present in Hoggett deposit in grades up to 1 percent WO_3.	
30	do	Peace	Tungsten-bearing psilomelane, hollandite, and cryptomelane in veins in Tertiary rhyolite porphyry.	Mode of occurrence of tungsten not not known.	Hewett and Fleischer, 1960.

Tungsten minerals have been reported from more than 30 localities throughout New Mexico, including old mining districts, new mines and prospects, and unimportant mineral occurrences. Total production from 1900 to 1955 is estimated at 104 short tons of ore and concentrate (60-percent WO_3 basis), which is about 0.06 percent of the national total (Holliday, 1960). Because of the small, piecemeal, and erratic nature of the production, an accurate breakdown of the record is impossible, but table 33, taken from a report of the U.S. Bureau of Mines by Dale and McKinney (1959), gives an estimate of tungsten production on a county basis. Most of this production was in the period 1913-18. None has been produced since 1957.

Tungsten minerals in New Mexico have been found in quartz veins, in pegmatites, in contact metamorphic (tactite) deposits, in shear zones as small crystals disseminated in brecciated igneous rocks, and associated in some unknown form with manganese oxide deposits. Small production has been made from each of the first three modes of occurrence.

Table 32 summarizes pertinent data on 30 occurrences. Additional occurrences of lesser importance might be listed. The numbers in the table refer to the localities shown on the map (fig. 51). The table and map are slightly modified from the section on New Mexico in "Tungsten in the United States" (Lemmon and Tweto, 1962).

New Mexico has never been an important producer of tungsten ; total production is only slightly more than 100 tons of concentrates (60 percent WO_3) (table 33). Tungsten deposits are characteristically in the form of pockets, usually of small size. Pods of ore may be of very high grade but of such small size and so erratically distributed in veins or other host rocks that the cost of exploration is greater than the value obtained. The deposits in New Mexico are generally of this type. However, the number, distribution, and wide variety of the deposits in the State emphasize the fact that the area is a part of a rather widespread tungsten province and the possibility of future discovery of economic concentrations should not be discounted.

Much of the major production of the United States in recent years has come from low-grade deposits of considerable size that are amenable to large-scale, low-cost mining, or else as a byproduct or coproduct of large-scale operations for other minerals. Of the known deposits in New Mexico, the one at Cunningham Hill in Santa Fe County may yield large-scale production, should the technology of recovery be solved and the price of tungsten be sufficient to make it profitable.

TABLE 33.—*Tungsten production in New Mexico by county*[1]

County	*60-percent TVO_3 concentrates (short tons)*
Colfax	16.0
Dona Ana	None
Grant	3.3
Hidalgo	9.6
Lincoln	56.8
Luna	19.6
Santa Fe	None
Sierra	7.0
Socorro	Unknown
Taos	1.5
Total	113.8

[1] Includes some figures that have no documentary evidence.

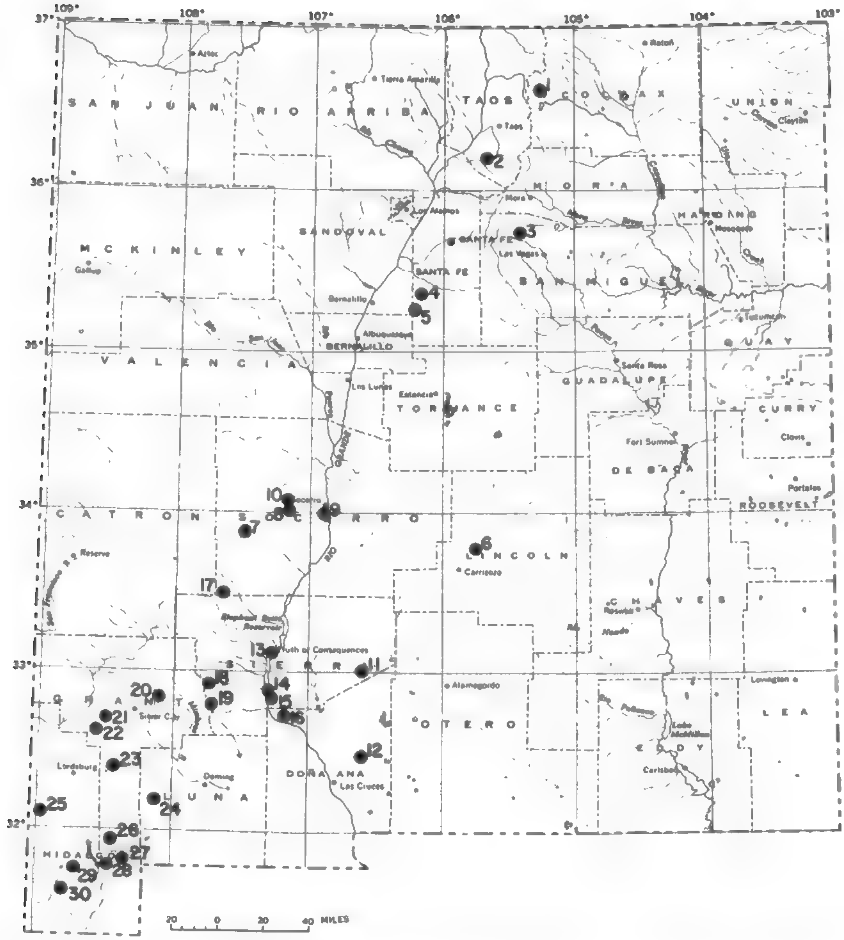


FIGURE 51.—Tungsten in New Mexico (numbers refer to localities listed in table 32).

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NONMETALLIC AND INDUSTRIAL MINERALS AND MATERIALS

BARITE

(By F. E. Williams, U.S. Bureau of Mines, Tucson, Ariz.)

Barite ($BaSO4$) is a heavy, nonmetallic material containing 65.7 percent barium oxide (BaO) and 34.3 percent sulfur trioxide (SO_3) that crystallizes in flat crystals having lateral dimensions several times their thickness. The mineral is translucent to opaque with a vitreous luster, commonly colorless to white, but sometimes in light shades of red, yellow, or blue. It is the heaviest nonmetallic mineral (specific gravity, 4.5), and its largest market depends on this property. Barite occurs in vein, replacement, and residual deposits either alone or, more commonly, in association with chert, jasper, quartz, fluorite, celestite, and various metallic sulfide and carbonate minerals.

Annual consumption of barite in the United States ranges between 1 and 1.5 million short tons, about 91 percent of which is used by the well-drilling industry as mud-weighting agent to aid in controlling high pressures encountered at depth ; about 4 percent is consumed by the glass industry and the remainder is chiefly used as filler for paint and rubber products. Other uses include filler for paper, textiles, linoleum, asbestos products, heavy aggregate for concrete products, paving material, and ceramics. Virtually all barite used in industry is consumed and is not recoverable. Quality control of barite raw materials varies for different uses ; however, for use as mud-weighting material, the crude barite must have a minimum specific gravity of 4.25. The current average price for crude barite (drilling-mud grade, 83 to 93 percent $BaSO_4$) is $12 to $16 per ton, f.o.b. shipping point, in carload lots. Ground barite sells for $26.75 per ton (Engr. & Mining Journ., 1964) .

Commercial production of barite in New Mexico began in 1918 but it has been insignificant compared with national production and consumption. Total known production of crude barite from New Mexico Is about 37,500 tons, 94 percent of which was produced from one mining property in Socorro County, the Mex-Tex group, in the period 1951-60. Average annual production by New Mexico during that period represented less than 0.4 percent of the Nation's average annual production. In 1963, total output amounted to 600 tons valued at $6,000. The barite, from the Elaine group of claims near Socorro, was sold as a weighting agent for drilling muds in the Farmington area. Barite produced in New Mexico has supplied limited local demands but barite from New Mexico cannot compete with other sources of barite in distant prime markets because of excessive transportation costs.

Barite in New Mexico occurs in veins or veinlets and as wall rock i
replacement in igneous, sedimentary, and metamorphic rocks, but chiefly of limestone. It is commonly associated with quartz or some

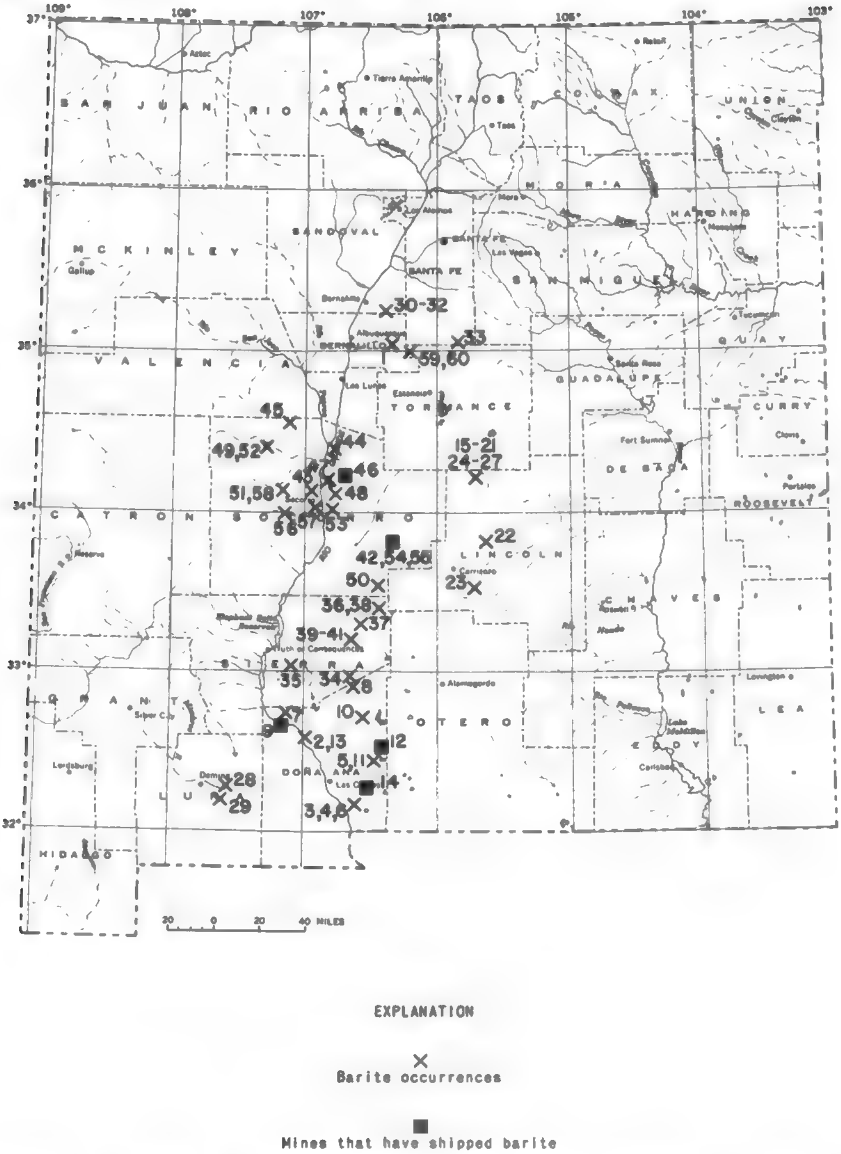

FIGURE 52.—Barite in New Mexico (numbers refer to deposits and occurrences listed in table 34).

other form of silica, fluorite, and metallic sulfides or carbonates. Some sandstones or breccias are cemented with barite. No residual-type barite ore bodies are known to occur in the State.

There are 60 known barite deposits and 24 other miscellaneous occurrences in 9 of the State's 32 counties (Williams and others, in preparation) . The locations of these are shown in figure 52 and listed in table 34 by counties. The miscellaneous occurrences include barite as a gangue constituent in sulfide ore bodies. Most of the barite reserves occur in north-trending mountain ranges of Socorro, Sierra, and Dona Ana Counties. The deposits are generally in readily ac-

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TABLE 34.—*Barite localities in New Mexico*

[Numbers identify symbols in fig. 52]

Bernalillo County:
1. P & G deposit

Dona Ana County:
2. Beal mine
3. Bishop Cap deposit
4. Blue Star deposit
5. Devil's Canyon deposit
6. Garcia & Morris deposit
7. Horseshoe deposit
8. Lot OM-69 deposit
9. Palm Park mine
10. San Andres lead mine
11. Silver Cliff deposit
12. Stevens mine
13. Tonuco mine
14. White Spar deposit

Lincoln County:
15. All American deposit
16. Big Ben deposit
17. Bottleneck deposit
18. Conqueror mine
19. Conqueror No. 4 deposit
20. Eagle Nest deposit
21. Eureka deposit
22. Fox Lode deposit
23. Helen Rae deposit
24. Hilltop deposit
25. Hoosier Girl deposit
26. Old Hickory mine
27. Red Cloud mine

Luna County:
28. Florida mine
29. Waddell deposit

Sandoval County:
30. Capulin Peak deposit

Sandoval County—Continued
31. Landsend deposit
32. Las Huertas deposit

Santa Fe County:
33. El Cuervo deposit

Sierra County:
34. American deposit
35. Carolyn (Paxton) deposit
36. Gem deposit
37. Lava Gap deposit
38. Salinas mine
39. Section 9 deposit
40. Section 29 deposit
41. Unnamed deposit

Socorro County:
42. Blanchard deposit
43. Box Canyon deposit
44. Dewey mine
45. Drake deposit
46. Elaine deposit
47. El Coyote deposit
48. Gonzales deposit
49. Helen deposit
50. Independence deposit
51. Jack Frost mine
52. Katherine deposit
53. La Bonita deposit
54. Mex-Tex deposit
55. Miera deposit
56. Sidewinder deposit
57. Torrence mine
58. Vanadium Friend deposit

Torrance County:
59. Shockley deposit
60. Tina deposit

Development of barite resources in New Mexico is dependent on demand and production costs. Much barite in New Mexico remains unmined because it is complexly associated with fluorite and not readily amenable to concentration. A relatively new method of effective separation of barite-fluorite complexes is raising submarginal deposits to the status of ore reserves in some regions (Bloom and others, 1963) . In the event that industrial demand shifts to New Mexico, or if larger deposits are found that can be mined more cheaply, New Mexico's barite may become competitive over a wider area of the Southwest.

FLUORSPAR

(By R. E. Van Alstine, Washington, D.C.)

Fluorspar, a mineral aggregate or mass containing enough fluorite (CaF_2) to be of commercial interest, is essential in the chemical aluminum, steel, and ceramic industries. It is presently the only important source of the indispensable element fluorine. In 1963 the United States consumed a record 736,000 tons of fluorspar (Ambrose, 1964).

Fluorite displays a vitreous lustre and a wide array of colors, commonly in shades of green or purple. It generally crystallizes as cubes or octahedrons but may occur in massive form, crusts, globular aggregates with radial fibrous textures, or banded cryptocrystalline forms resembling chalcedony, with which it may be associated. Fluorite has perfect octahedral cleavage, and this property, together with its crystal forms, color, heaviness, and hardness, distinguishes it from other minerals. It is softer than quartz and harder than calcite, two common minerals with which it may be confused; and it is appreciably heavier than either one.

Chemical research, based on the fact that fluorine chemicals have unsurpassed reactivity and energy under certain conditions and unsurpassed inertness under others, is yielding a growing variety of fluorine chemicals that are used in increasing quantities. Hydrofluoric acid, made by treating fluorspar with sulfuric acid, is the basis for most of these chemicals. Inorganic fluorides are used extensively in insecticides, preservatives, dieletrics, fluoridation of drinking water, and the production of uranium. Organic fluorides, which are fluorinated hydrocarbons or fluorocarbons, serve as refrigerants, air conditioners, aerosol propellants, resins, elastomers, plastics, drugs, oils,. greases, waxes, and many other widely used products. Hydrofluoric acid is also employed as a catalyst in the manufacture of alkylite, an ingredient in high-octane aviation and automobile fuels.

In the aluminum industry, fluorspar is converted to aluminum fluoride and synthetic cryolite, which serve as the electrolyte in the reduction of alumina to aluminum metal. About 140 pounds of the highest grade fluorspar converted to these fluorides is used in the production of each ton of aluminum metal.

Fluorspar is essential to the steel industry as a flux in basic openhearth, basic oxygen, and electric furnaces, where it reduces the viscosity of the slag and facilitates removal of phosphorus and sulfur from the steel. From 3 to 16.5 pounds of fluorspar is used for each ton of steel produced (Kuster, 1963, p. 567) .

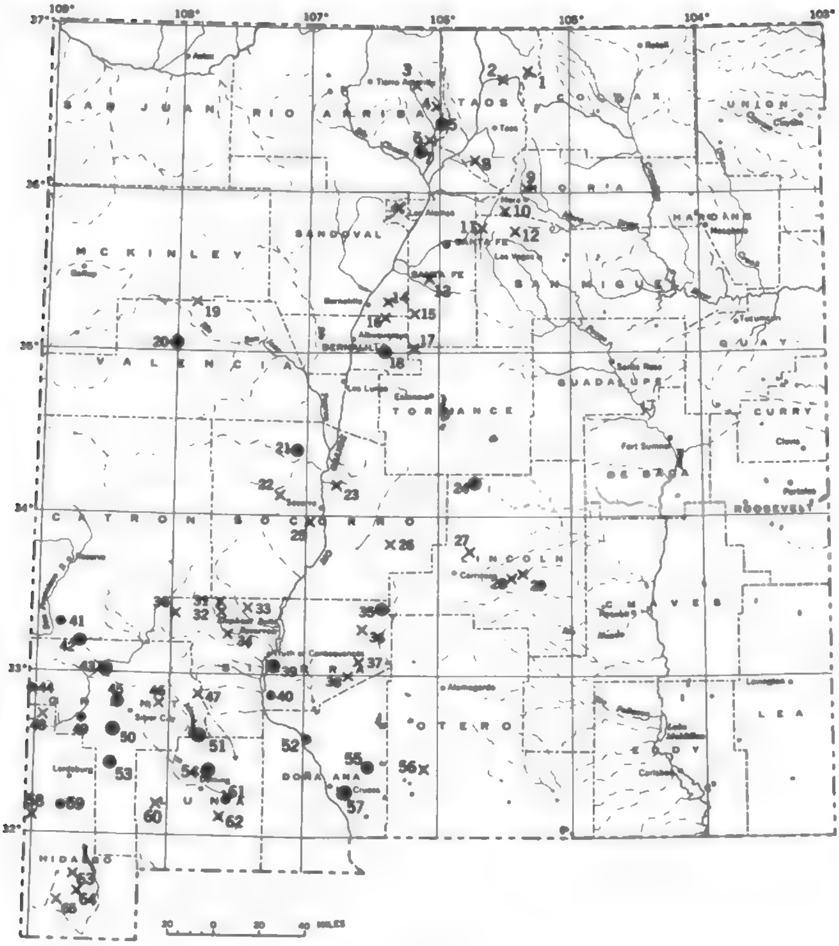
In the ceramic industry fluorspar is invaluable in the manufacture of opal container glass and enamels for coating steel or cast iron, used in stoves, refrigerators, cooking ware, bathtubs, sinks and cabinets.

Fluorspar is marketed in acid, ceramic, and metallurgical grades. Acid-grade fluorspar, used for making hydrofluoric acid, is the highest grade and contains at least 97 percent CaF_2 and only very limited quantities of silica, carbonates, and sulfur. Specifications for ceramic-grade fluorspar depend partly on the buyer's requirement; generally acceptable material contains at least 93 to 95 percent CaF_2 not over 2.5 percent silica, less than 0.12 percent ferric oxide, and limited carbonates. Metallurgical-grade fluorspar must contain more than 60 per-

cent effective calcium fluoride and generally not more than 0.3 percent sulfur or 0.5 percent lead. Effective calcium fluoride content is determined by subtracting from total calcium fluoride, 2.5 percent of calcium fluoride for each percent of silica. Of the approximately 653,000 tons of fluorspar consumed in the United States in 1962, about 57 percent was acid grade, 37 percent was metallurgical grade, and 6 percent was ceramic grade (Kuster, 1963, p. 566).

The United States is the world's leading consumer of fluorspar and for many years it was the largest producer. Since 1952 foreign imports have exceeded domestic production and in 1962 imports amounted to nearly 600,000 tons, approximately three times domestic production (Kuster, 1963, p. 561). About 75 percent of the 1962 imports came from Mexico, which, since 1956, has been the leading fluorspar producer; Spain and Italy supplied almost all of our other fluorspar imports.

The numerous fluorspar deposits of New Mexico are localized mainly in the southwestern and central parts of the State. Sixty-five areas, ranging from minor occurrences to groups of several important deposits, are shown in figure 53. Fluorspar has been produced at 24 of these areas, with 87 percent of the production from 7 areas, 10 percent from 7 additional areas, and 3 percent from the remaining 10 areas.



EXPLANATION

Area with major production (more than 20,000 tons crude fluorspar)

Area with moderate production (5,000-20,000 tons crude fluorspar)

Area with minor production (less than 5,000 tons crude fluorspar)

Fluorite occurrence (principally associated with deposits of value for other materials)

FIGURE 53.—Fluorspar in New Mexico.

Fluorspar localities in New Mexico

[Numbers identify symbols in fig. 531

1. Independence mine (Au, Ag, Cu)'
2. Questa area (Mo)
3. Bromide district (Cu, Au)
4. Petaca district (Peg.)
5. La Madera deposit (F)
6. Ojo Caliente district (F, Peg.)
7. El Rito deposit (F)
8. Harding mine (Peg.)
9. Cleveland prospect (F)
10. Rociada district (Peg.)
11. Willow Creek district (Peg., Cu)
12. El Porvenir district (Peg.)
13. Cerrillos district (Pb, Ag, Cu, Au)
14. Placitas district (Pb, Cu)
15. Carnahan mine area (Pb, Zn)
16. Sandia Mountains prospects (F)
17. Tina deposits (Ba)
18. Manzano Mountains deposits (F)
19. Grants district (U)
20. Zuni Mountains deposits (F)
21. Juan Torres deposit (F)
22. Magdalena district (Pb, Zn)
23. Socorro area prospects (F)
24. Gallinas district (F, Fe, Pb, Cu, R.E.)
25. Luis Lopez district (Mn)
26. Hansonburg district (Pb, Ba)
27. Lone Mountain area prospects (F, W)
28. Capitan Mountains deposits (Fe)
29. Capitan Mountains deposits (Th)
30. Black Range district (Sn, Be)
31. Iron Mountain district (Fe, Be, W, Zn)
32. Fairview prospect (F)
33. Terry prospect (U)
34. Sierra Cuchillo prospects (F)
35. Lava Gap deposit (F)
36. Salinas and Valle Vista prospects (F)
37. Cave Spar prospect (F)
38. American prospect (F)
39. Northern Sierra Caballos deposits (F, Pb, V)
40. Southern Sierra Caballos deposits (F)
41. Huckleberry deposit (F)
42. Southern Mogollon Mountains deposits (F)
43. Gila district (F)
44. Steeple Rock district (F)
45. Silver City area deposits (F)
46. Fierro-Hanover district (Zn)
47. Carpenter district (Pb, Zn, Be)
48. Big Nine prospect (F)
49. Red Rock district (F)
50. Burro Mountains district (F)
51. Cooks Peak district (F)
52. Tonuco deposit (F)
53. White Signal-Gold Hills district (F, U)
54. Fluorite Ridge district (F)
55. Organ-San Andres Mountains deposits (F)
56. Orogrande district (Cu, Fe)
57. Tortugas deposit (F)
58. Peloncillo Mountains prospects (F)
59. Pyramid Mountains deposits (F)
60. Victorio district (W, Be)
61. Little Florida Mountains deposits (F)
62. Waddell prospect (F)
63. Hoggett prospect (F)
64. Volcano prospect (F)
65. Peace prospect (Mn)

Chief mineral products or geological association as follows :

Ag-silver	Fe- iron	Sn-tin
Au-gold	Mn-manganese	Th-thorium
Ba-barite	Mo-molybdenum	II-uranium
Be-beryllium	Pb-lead	V-vanadium
Cucopper	Peg.pegmatites	W tungsten
F-fluorspar	R.E.-rare earths	Zn-zinc

Fluorspar production in New Mexico began in the early 1880's in the Burro Mountains and Gila districts. It reached a peak in 1944 when the mines throughout the State yielded about 100,000 short tons of crude ore from which about 43,000 tons of marketable fluorspar was shipped (Davis and Greenspoon, 1946, p. 1404). About 40 percent of New Mexico's fluorspar production was mined between 1940 and 1945 and, during World War II, New Mexico was the fourth leading fluorspar producer, after Illinois, Kentucky, and Colorado.

As tabulated from records of the U.S. Geological Survey and the Bureau of Mines (Minerals Yearbooks; F. E. Williams, written communication, 1964), the total mine production of fluorspar in New Mexico through 1954, the latest year of significant production, has amounted to about 670,000 short tons. Total shipments of commercial fluorspar from the earliest record to the end of 1954 amounted to 382,611 short tons, which is 4.2 percent of the U.S. shipments to that date (Holtzinger and Roberts, 1958, p. 463). These shipments were mainly metallurgical- and acid-grade concentrates that went to the steel industry at Pueblo, Colo., to the chemical industry, and to the U.S. Government stockpiles. The highest annual average value for fluorspar concentrates from New Mexico was reported as $50.04 per ton for 1952 (Holtzinger and Roberts, 1956, p. 464) .

Fluorspar production in New Mexico essentially ceased in 1954, largely because of depressed prices and inability to meet foreign competition. New Mexico has substantial fluorspar resources, and when prices increase sufficiently, the State should once again have a sizable fluorspar industry.

The seven areas of major fluorspar production shown in table 35 are closely associated spatially and possibly genetically with intrusive or extrusive igneous rocks of Late Cretaceous or Tertiary age, and are near the edges of uplifts or depressions formed during those ages. They are localized chiefly in Tertiary intrusive and extrusive rocks, Precambrian granites, and Paleozoic sedimentary rocks ; adjacent to the fluorspar deposits the wall rock is commonly silicified, sericitized, or fluoritized. The fluorspar deposits are veins and mineralized breccias along faults and are considered to be epithermal, having formed at relatively low temperatures and pressures near the earth's surface.

The ores range in grade from approximately 35 to 85 percent CaF2; a typical ore contains about 60 percent CaF_2 20 percent. SiO_2, and 20 percent $CaCO_3$. Quartz, chalcedony, calcite, and clay are commonly associated with the fluorite in the deposits; barite and galena generally are rare. Lead and vanadium, occurring as vanadinite and descloizite, were mined from several fluorspar deposits in the northern Caballo Mountains (Hess, 1913). Manganese-oxide minerals have been found together with fluorite at the Tortugas deposit (No. 57) (Rothrock, Johnson, and Hahn, 1946, p. 55) ; in the Little Florida Mountains deposits (No. 61) (Griswold, 1961, p. 132) ; in the southern Caballo Mountains deposits (No. 40) (Farnham, 1961, p. 127) ; and at the west edge of the Burro Mountains district (No. 50) in a deposit that probably was formed in part by hot springs (Gillerman, 1952, p. 279).

Individual ore bodies generally are small and commonly contain 20,000 to 35,000 tons of fluorspar, according to computations based

TABLE 35.—*Areas of major fluorspar production*

[More than 20,000 tons crude fluorspar]

Map locality No.	Name	Country rock	Production intermittently	Chief products [1]	Selected references
20	Zuni Mountains	Precambrian granite	1918–53	A, M	Rothrock, Johnson, and Hahn, 1946, pp. 176–190; Goddard, 1952.
39	Northern Sierra Caballos	Precambrian granite and Paleozoic limestones, sandstones, and shales.	1918–54	M, A	Rothrock, Johnson, and Hahn, 1946, pp. 148–163; Kelley and Silver, 1952, p. 199.
43	Gila	Tertiary latitic and andesitic flows and agglomerate.	Early 1880's to 1953	M, A	Rothrock, Johnson, and Hahn, 1946, pp. 80–98.
50	Burro Mountains	Precambrian granite	Early 1880's to 1954	A, M	Rothrock, Johnson, and Hahn, 1946, pp. 69–73; Gillerman, 1952.
51	Cooks Peak	Precambrian granite and Tertiary(?) andesite	Before 1918 to 1954	A, M	Rothrock, Johnson, and Hahn, 1946, pp. 98–103; Elston, 1957, pp. 65–71.
54	Fluorite Ridge	Tertiary monzonite porphyry, basalt, agglomerate, and clastics.	1909–54	A, M	Rothrock, Johnson, and Hahn, 1946, pp. 126–142; Darton and Burchard, 1911.
57	Tortugas	Pennsylvanian limestones and shales	1919–43	M, C	Rothrock, Johnson, and Hahn, 1946, pp. 54–56; Johnston, 1928, pp. 75–82.

[1] A—Acid-grade fluorspar; M—Metallurgical-grade fluorspar; C—Ceramic-grade fluorspar.

on the average dimensions of about 40 deposits (Rothrock, Johnson, and Halm, 1946, p. 21). Some productive veins are several thousand feet long, and the Burro Chief deposit in the Burro Mountains (No. 50) was explored to a depth of 800 feet with no change in the character or tenor of the ore (Gillerman, 1952, p. 275).

Fluorspar has been mined and marketed from 17 additional areas shown in figure 53. The geologic setting and mineralogy of most of the deposits at these smaller centers of production are similar to those described in table 35 (Johnson, 1928; Rothrock, Johnson, and Hahn, 1946; Gillerman, 1952). La Madera (No. 5) and El Rito (No. 7) deposits in Rio Arriba County, two centers of minor production not described in publications, are possibly the geologically youngest fluorspar deposits mined in New Mexico, as they are localized in gravel, siltstone, and volcanic rocks of the ganta Fe Group (Just, 1937, pl. 3; Dane and Bachman, 1957). The fluorspar occurs mainly as crusts and veinlets and as small irregular-shaped bodies in brecciated and altered zones along faults. Deposits exposed in limited workings in 1956 contain an estimated 10 to 50 percent CaF_2. About 1,000 tons of handpicked fluorspar containing more than 65 percent CaF2 was shipped from these deposits to a flotation mill at Los Lunas, N. Mex. (oral communication, G. A. Warner of Zuni Milling Co., and Tomas Triejo of Ojo Caliente, N. Mex.) .

Some of the fluorite occurrences shown on the index map are prospects consisting of small or low-grade isolated veins that were unprofitable to mine (Johnson, 1928 ; Rothrock, Johnson and Hahn, 1946; Gillerman, 1958). At other localities the fluorite occurs in deposits mined or explored for other mineral commodities (table 36). Fluorite, for example, is present in New Mexico in pegmatites and in deposits of barite, lead, zinc, copper, gold, silver, iron, manganese, tungsten, molybdenum, tin, uranium, thorium, beryllium, and rare earths. Lead-barite ore in part of the Hansonburg district (No. 26) contains 12 to 23 percent CaF_2 (Kottlowski, 1953, p. 7), and fluorspar may be recovered eventually as a byproduct or coproduct here and from other localities.

The probable reserves of fluorspar in New Mexico were estimated by Burchard (1933, p. 20) to be 400,000 short tons of metallurgical-grade concentrates. In 1956 the writer estimated the measured, indicated, and inferred reserves of fluorspar in New Mexico to be about 1.4 million tons of ore containing at least 35 percent CaF_2, and inferred another million tons of material containing 15 to 35 percent CaF_2 (Office of Minerals Mobilization and U.S. Geological Survey, 1956). About 85 percent of the higher grade ore and 80 percent of the lower grade material are located in the seven areas of major production (fig. 53), in the Gallinas district No. 24), and in the southern Caballo Mountains deposits (No. 40).

More fluorspar discoveries are expected in New Mexico when economic conditions in the domestic industry are more favorable for further search and exploration. Although exploration probably will be directed chiefly toward areas with previous production, the margins of metalliferous districts should also receive attention. Dunham (1935, p. 137) and Loughlin and Koschmann (1942, p. 103) have called attention to the occurrence of fluorite and barite in the outlying parts of the Organ and Magdalena lead-zinc districts. Hewett suggests that manganese oxide-carbonate minerals, fluorite, barite, and minor metal

TABLE 36.—*Fluorite in deposits of other mineral commodities*

Map locality No.	Name	Chief associated commodities	Selected references
1	Independence mine	Gold, silver, copper	Lindgren, 1933, pp. 166, 176.
2	Questa area	Molybdenum	Schilling, 1956, pp. 42, 56, 68, 71, 72; Schilling, 1960, p. 114.
3	Bromide district	Copper, gold	Lindgren, 1933, pp. 167, 176.
4	Petaca district	Pegmatites	Jahns, 1946, p. 62, table 3.
6	Ojo Caliente district	do	Jahns, 1946, pp. 270–274.
8	Harding mine	do	Jahns, 1953, p. 1090.
10	Rociada district	do	Do.
11	Willow Creek district	Pegmatites, copper	Northrop, 1959, p. 243; Lindgren, Graton, and Gordon, 1910, p. 114.
12	El Porvenir district	Pegmatites	Anderson, 1956, p. 141; Northrop, 1959, p. 243.
13	Cerrillos district	Lead, silver, copper, gold.	Lindgren, 1933, p. 167.
14	Placitas district	Lead, copper	Ellis, 1922, pp. 41–42.
15	Carnahan mine area	Lead, zinc	Atkinson, 1961, p. 37.
17	Tina deposit	Barite	Written communication, Williams, F. E., U.S. Bureau of Mines, 1964.
19	Grants district	Uranium	Gableman, 1956, p. 396; Hilpert and Moench, 1960, p. 447; Laverty and Gross, 1956, p. 200.
22	Magdalena district	Lead, zinc	Loughlin and Koschmann, 1942, pp. 103, 159.
24	Gallinas district	Iron, lead, copper, rare earths.	Rothrock, Johnson, and Hahn, 1946, pp. 110–122; Kelley, 1949, p. 174; Griswold, 1959, pp. 23–25, 64–66; Perhac and Heinrich, 1964.
25	Luis Lopez district	Manganese	Hewett and Fleischer, 1960, p. 28.
26	Hansonburg district	Lead, barite	Kottlowski, 1953, p. 7; Rothrock, Johnson, and Hahn, 1946, pp. 175–176.
27	Lone Mountain area	Tungsten	Lindgren, 1933, p. 166; Northrop, 1959, p. 241.
28	Capitan Mountains	Iron	Kelley, 1949, p. 150.
29	do	Thorium	Griswold, 1959, p. 88–91.
30	Black Range district	Tin, beryllium	Fries, 1940, pp. 364–365.
31	Iron Mountain district	Iron, beryllium, tungsten, zinc.	Kelley, 1949, pp. 198–202; Jahns, 1944, p. 61.
33	Terry prospect	Uranium	Lovering, 156, pp. 368–371.
39	Northern Sierra-Caballos deposits.	Lead, vanadium	Rothrock, Johnson, and Hahn, 1946, p. 159; Hess, 1913.
46	Fierro-Hanover district	Zinc	Schmitt, 1939, p. 812.
47	Carpenter district	Lead, zinc, beryllium	Warner et al., 1959, pp. 114–116.
53	White Signal-Gold Hills district.	Uranium	Lovering, 1956, pp. 352, 353; Gillerman, 1952, p. 285.
56	Orogrande district	Copper, iron	Kelley, 1949, pp. 181, 183, 185.
60	Victorio district	Tungsten, beryllium	Warner et al., 1959, p. 122–125.
65	Peace prospect	Manganese	Farnham, 1961, p. 47.

sulfides formed during late Tertiary time in the higher and cooler zones of the base-metal districts in New Mexico and elsewhere in western United States (Hewett and Fleischer, 1960, p. 50). Additional aids to prospecting for fluorspar in New Mexico have been described by Rothrock, Johnson, and Hahn (1946, p. 34-35).

GEM MATERIALS

(By M. D. Carter, U.S. Geological Survey, Washington, D.C.)

Gem materials are naturally occurring substances that are used as gem or ornamental stones. Gem stones are used for personal adornment. Ornamental stones are used for decorative purposes. The degree to which gem materials possess beauty, rarity, and durability determines their value. Precious stones, which for centuries have included diamond, emerald, ruby, and sapphire, possess all three of the major qualities mentioned above. Semiprecious materials may possess one or two, or perhaps lesser degrees of all three, of the major qualities. The dividing point between the two categories is arbitrary and may vary according to taste. As defined above, precious gem materials do not occur in New Mexico, whereas a wide variety of semiprecious materials occur throughout the State.

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Taste and fashion vary, so that only precious stones may be assured of a perpetual market. In New Mexico no gem material has been in constant production for a long period of time. For centuries garnet, peridot, and turquoise were collected haphazardly, mainly by Indians. In 1889 the first systematic gem-material mining began in New Mexico. Turquoise was actively mined from then until the deposits were largely exhausted in the early 20th century. Garnet, peridot, smithsonite, and staurolite have been produced sporadically, whenever demand seems great enough. In the years following the depression through World War II there was little demand for gem materials. With the rising economy after the war, this demand increased, and the less expensive and more accessible quartz materials came into great demand. Agate has become the most popular and actively produced gem material, followed by jasper, chalcedony, and pertrified wood.

During 1962 New Mexico produced gem materials from 12 of its 32 counties. Luna County was the principal source, accounting for one-third of the New Mexico production. Agate was the principal material collected. Amethyst, aragonite, chalcedony, quartz crystals, jasper, Mexican onyx, smithsonite, turquoise, and petrified wood were also collected. In that year New Mexico ranked 10th in the United State in total gem material production, 2d in turquoise, 3d in agate, among the first 3 in mineral specimen output with 25,000 pounds, and 7th in petrified wood.

The gem industry is now operated by individuals rather than companies and by more amateurs than professionals. Due to this trend, production statistics and location of deposits have become increasingly difficult to obtain. Production figures have always been incomplete, since amateurs rarely report their finds and data are frequently estimated. The figures in table 37 are, therefore, much lower than the actual value of gem material produced in New Mexico.

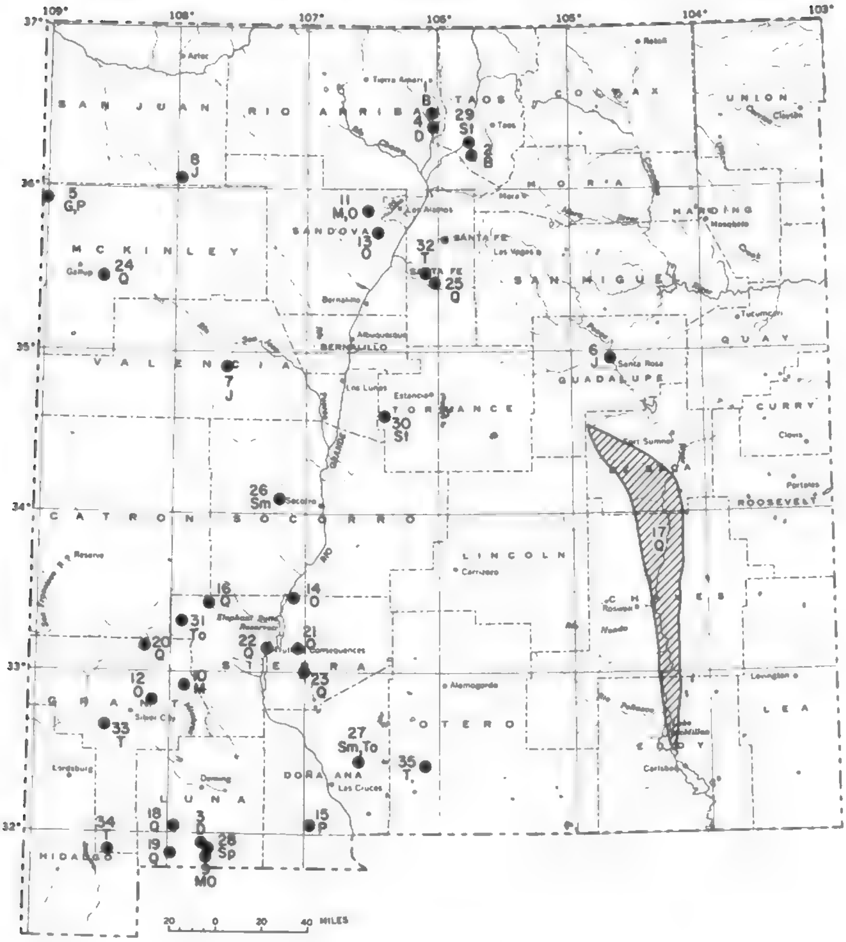
The following discussion includes only the better known deposits, with approximate locations. The gem materials are discussed alphabetically for convenience of reference. Numbers in the text refer to localities shown in figure 54.

TABLE 37.—*Gem material production in New Mexico, 1890–1963*

Year	Value	Year	Value
1890	$10,000	1915 [2]	--------
1891	150,000	1916	$675
1892	175,000	1917 [2]	--------
1893 [1]	200,000	1918	1,079
1894 [1]	250,000	1919 [2]	--------
1895 [1]	350,000	1920	1,315
1896 [1]	475,000	1921–54 [2]	--------
1897–1901	--------	1955	25,000
1902 [3]	51,600	1956	30,000
1903–05 [2]	--------	1957	30,000
1906	16,000	1958	28,000
1907	1,570	1959	39,000
1908	72,100	1960	40,000
1909	25,636	1961	46,000
1910	16,800	1962	45,000
1911	26,655	1963 [4]	45,000
1912	795		
1913	3,350	Total (1890–1963)	2,155,630
1914	55		

[1] Otero, 1900, p. [redacted]
[2] Figures not available or production not canvassed.
[3] Jones, 1904, p. 346.
[4] Preliminary data.

Source: U.S. Geological Survey and U.S. Bureau of Mines.



EXPLANATION

B	Beryl	P	Peridot
D	Dumortierite	Q	Quartz
G	Garnet	Sm	Smithsonite
J	Jet	Sp	Spurrite
MO	Mexican onyx	St	Staurolite
M	Moonstone	To	Topaz
O	Opal	T	Turquoise

FIGURE 54.—Gem materials in New Mexico (numbers refer to localities discussed in text).

BERYL

Two varieties of gem beryl, a beryllium aluminum silicate, have been found in New Mexico pegmatites. They are of value particularly as museum specimens. Aquamarine is the semiprecious bluish-green variety which occurs in elongate crystals. Morganite, the pale pink or pinkish yellow semiprecious variety occurring as short, tabular crystals. Pale to deep green aquamarine has been obtained during mining for common beryl at the Sunnyside mine (No. 1) in the Petaca district of Rio Arriba County. Crystals up to 6 feet in length and 7 inches in diameter contain many patches of facet-grade material (Sinkankas, 1959, p. 85). Museum quality aquamarine crystals several inches long and three-quarters inch across have been recorded from the Harding mine (No. 2) in Taos County during small-scale mining for common beryl. Morganite, some similar to rose quartz and some with a slight yellowish-violet tint, has also been found in the Harding mine (Northrop, 1959, p. 139). Crystals of aquamarine and morganite are present in numerous beryl deposits in the State (see beryllium chapter). Past reports of precious emerald occurrences in New Mexico appear to have been the result of misidentification of peridot.

DUMORTIERITE

Dumortierite is a rather rare aluminum borosilicate. It is transparent to translucent occurring in various shades of blue in fibrous to columnar aggregates and sheaflike forms (Northrop, 1959, p. 222). Dumortierite was discovered in New Mexico in 1916 south of the Mahoney mining area in the Tres Hermanas Mountains (No. 3) , Luna County. This is the major of the two known occurrences in the State. The dumortierite occurs in a quartz vein several feet wide which outcrops for over 1,000 feet. The mineral occurs in narrow blue seams one-quarter inch wide and the same distance apart. Schaller (1919, p. 893) stated that the deposit should yield a striking ornamental stone with the seams of bright blue dumortierite in contrast to the surrounding white rock. Selected pieces with a narrow band of dumortierite could be cut and polished as handsome semiprecious gem stones. Steel-gray lapidary-quality dumortierite with a dark bluish-lavender tint was reported in 1954 in the Petaca district (No. 4) about one-half mile southeast of La Madera in Rio Arriba County (Northrop, 1959, p. 222).

GARNET

Garnet includes a group of six minerals with similar physical properties, cryStal forms, and a basic chemical formula in which certain elements replace each other to form a series. Gem quality garnet may include any one of several varieties. Although all varieties of garnet have been found throughout the State, few occurrences contain gem grade crystals and these are not in concentrations offering commercial possibilities. Pyrope, a magnesium aluminum silicate ranging in color from deep ruby-red to nearly black, is the most popular garnet and is prized as a gem stone. Blood-red pyrope from the Red Lake volcanic field-Buell Park area (No. 5) along the Arizona-New Mexico border about 10 miles north of FortDefiance has long been admired. This pyrope along with peridot is found loose

in ant hills and in the alluvium and gravels on the Navajo Reservation of McKinley County. Here the pyrope has weathered out of the surrounding volcanic kimberlite tuffs. The quality of the pyrope is excellent, but, as crystals over three-sixteenths inch in diameter are rare, commercial exploitation is impractical. Although there is no organized production, tourists passing through the Gallup area have purchased pyrope gathered by the Indians at the rate of several hundred dollars annually (Talmage and Wootton, 1937, p. 84). Despite long collecting, the pyrope supply is far from exhausted. The Indians are easily able to supply current demand. However, the majority of the garnets on the market in New Mexico probably come from the Arizona portion of the reservation.

JET

Jet, a black variety of brown coal or lignite, is light in weight, soft, and yet compact enough to be carved into numerous designs and to take a velvety polish. Jet was extremely popular during the Victorian era and again during the 1920's both as mourning jewelry and for ornaments. Deposits have been reported in three areas of New Mexico from which jet might be extracted should the market warrant. Jet occurs in the vicinity of Santa Rosa (No. 6) in Guadalupe County (Jones, 1904, p. 343). Seams of cannel coal up to 20 inches thick, which long ago provided Indians with jet, ornaments, have been found in Valencia County near Acoma (No. 7). It is also present in the Chaco Canyon area (No. 8) and has been found in excavations of ancient Indian sites in San Juan County. New Mexico is one of the few States in the Nation in which workable deposits have been found.

MEXICAN ONYX

Mexican onyx or onyx marble is a popular term applied to fine-grained masses of calcite (calcium carbonate) formed by cold water solution. Mexican onyx is more dense than ordinary calcite and can be used for book ends, table tops, and other ornamental objects. A deposit of commercial grade is located on the south slopes of the Tres Hermanas Mountain (No. 9) about 4 miles west-northwest of Columbus in Luna County (Griswold, 1961, p. 145). The deposit, occurs as thick, short veins of creamy white to honey yellow material with a slightly pinkish cast,. Blocks up to 5 feet in diameter have been extracted and sent to Columbus where they were cut and polished as interior building stone. A few ornamental objects have been produced and sold from this deposit. The majority of onyx production in New Mexico has come from the Luna. County deposit, but there is a substantial suppply of Mexican onyx for the collector. It also occurs in caverns in Dona Ana and Eddy Counties as well as in various districts in Grant and Sandoval Counties (Northrop, 1959, p. 163, 164).

MOONSTONE

Moonstone, an intergrowth of orthoclase and albite valued for its pearly bluish opalescent luster, is a semiprecious gem stone known in two localities in New Mexico. The Rabb Canyon moonstone pegmatites of the Black Range (No. 10) in Grant County yield some of the finest moonstones in North America (Sinkankas, 1959, p. 149).

The glassy gem quality material is found in the interior of opaque white sanidine crystals. The moonstone is smoky gray or brown and exhibits intense bright blue, and occasionally silvery, adularescence along one direction. These deposits were discovered in the 1920's and have been worked intermittently since then. The moonstone usually is so cracked that large flawless gems cannot be obtained. Although the output of gem material has been small, a sizable amount has been sold by several large mineral companies as mineral specimens due to its outstanding play of colors (Kelley and Branson, 1947, p. 700). Superb blue moonstone is widespread and abundant in the volcanic rock in the Jemez region (No. 11) of Sandoval County. According to Northrop (1959, p. 390) a "striking feature of the entire Jemez Plateau is the abundance of iridescent sani dine crystals in soil, in alluvium, and especially in ant hills."

OPAL

Opal is a weak, brittle, heat-sensitive easily scratched hydrous silicon dioxide frequently associated with volcanic rocks. When it displays a delicate play of colors known as opalescence it is highly prized as a semiprecious gem stone. Fire opal is a red to yellow form that displays dazzling firelike reflections. Good fire opals have been reported from the Central district one-half mile from Fort Bayard Station (No. 12) and nearby from the Santa Rita district (No. 12), both in Grant County. The Fort Bayard deposit, in hard volcanic rock, was prospected in 1906 and proved to contain beautiful white "button opal" containing little fire but making fine specimens due to a consistent outline by a zone of black chalcedony (Sterrett, 1907, p. 1227). Precious opal also occurs in a matrix of hydrated quartz over a 16-square-mile area in the Cochiti district (No. 13) of Sandoval County. Most of this deposit is "wood opal" in which the opal has replaced woody material. White, gray, and green opalized wood is present in volcanic tuff near Battleship Rock (No. 11) in the Jemez Sulphur district also of Sandoval County. Wood opal suitable for gem cutting occurs in the Jornada del Muerto at the north end of the Fra Cristobal Range (No. 14) in Sierra County.

PERIDOT

Peridot, a magnesium silicate, is the transparent well-crystallized semiprecious gem variety of olivine found in dark volcanic rocks. The most prolific source is in the Buell Park area in the Red Lake volcanic field of Arizona, but the necks and dikes just inside the New Mexico border at the foot of Red Lake (No. 5) on the Navajo Reservation in McKinley County have yielded fine yellow-green peridot (Gregory, 1917, p. 146). Gem grade peridots up to one or two carats have been found in ant hills of this area. In Dona Ana County pale green nodular masses of peridot occur in the basalt flows of the Kilbourne Hole (No. 15) near Afton. The nodules found around this extinct volcano average about 2 inches in diameter and, although badly shattered, have yielded small but handsome gems (Sinkankas, 1959, p. 207). A faceted peridot of 3.4 carats from the flow was reported m 1949 (Northrop, 1959, p. 381) .

QUARTZ

Quartz, a silicon dioxide, is the most abundant of all minerals. In New Mexico it is present in sedimentary, igneous, and metamorphic rocks in every county and district. Quartz is of considerable economic importance in the State although the cut gems rarely bring high prices. The quartz group is divided into two categories; phenocrystalline and cryptocrystalline. Phenocrystalline quartz consists of large distinctive transparent crystals from which faceted gems may be cut. Cryptocrystalline quartz, opaque to translucent, massive, and composed of microscopic crystals, is suitable for cabachons and various ornamental objects. The occurrences of quartz are so numerous and details of them so vague that only the most notable are discussed (see Northrop, 1959, p. 420-437; Sinkankas, 1959, p. 366, 368; and Simpson 1961).

Two varieties of phenocrystalline quartz are of importance in New Mexico; amethyst and Pecos Valley "diamonds." Purple to bluish-violet amethyst occurs throughout the mountainous regions of New Mexico, and is abundant in the Chloride district (No. 16) of Sierra County; however, the mineral has never been developed commercially (Talmage and Wootton, 1937, p. 83). Pecos Valley "diamonds" most often occur as doubly terminated hexagonal prisms which weather out of gypsum beds along the Pecos River Valley (No. 17) in De Baca, Chaves, and Eddy Counties. The crystals themselves are valued as souvenirs from the Pecos Valley region, for jewelry, and as decorations for ornamental objects (Albright and Bauer, 1955, p. 346).

Three varieties of cryptocrystalline quartz have been produced in New Mexico; chalcedony, jasper, and pertified wood. Chalcedony is compact and transparent to translucent in dull shades of white, gray, blue, brown, and black with a waxy luster. It is deposited from aqueous solutions as lining or filling of cavities. Chalcedony was used extensively for artifacts by the early Indians and is widely collected at present. There are no outstanding collecting or producing deposits of chalcedony, but it can be found in gravels almost anywhere in the State.

Agate, due to its colorful inclusions, is a much more sought-after form of chalcedony. Agate is the source of the majority of the New Mexico gem trade. The principal producing area is near Deming in Luna County. The U.S. Bureau of Mines shows production from this area of over $10,000 per year from 1955 to 1957. The most notable deposit in the Deming area is in the Burdick Hills (No. 18) where well-banded colorless, white, gray, blue-gray, brown, and reddish-brown agate occurs as veinlets and small pods in a volcanic tuff (Griswold, 1961, p. 144). The deposit has been mined extensively with bulldozers followed by hand picking. In the same county "thunder-egg" agate in nodules up to 1 foot in diameter is present in altered latite flows and tuffs about 1 mile northwest of Hermanas (No. 19). The "Jeffers Agate Field" (No. 20) north of Silver City in Grant County has produced plume, flower, and carnelian agate as well as clear chalcedony and dark red jasper since it was discovered (Neely, 1946b, p. 431). Orange, red, blue, and black flower, ribbon, fern, fortification, moss, and sagenite agate have been collected in the Jornada del Muerto (No. 21) 13 miles east of Truth or Consequences

in Sierra County. The supply of agate is almost limitless for the amateur collector. Flash floods constantly rework the gravels revealing fresh material.

Jasper is a red, sometimes yellow, blue, or green, iron-stained, opaque variety of cryptocrystalline quartz. Folsom points have been chipped from this material. Gem quality red-, yellow-, and brown-banded jasperoid has been obtained from limestone in the Candy Rock strip mine (No. '22) in the Hot Springs district of Sierra County. This material is also known as Hot Springs "wonderstone" or "picture rock." Gem grade jasper and jaspagate occur near the Aleman Ranch (No. 23) 15 miles south of Engle in Sierra County (Neely, 1946a, p. 139).

Petrified wood is formed by the replacement of the woody matter with various forms of silica usually of the quartz family. Properly called silicified wood, it is generally used for ornamental objects but occasionally can be cut as cabachons. In McKinley County silicified wood resembling that of the Arizona Petrified Forest occurs in the Triassic rocks of the Zuni Mountains in the vicinity of Fort Wingate (No. 24). Sweet's Ranch Petrified Forest (No. 25), 3 miles east of Cerrillos in Santa Fe County, covers a large area and contains much gem-grade fossil wood. Gem-grade material has been obtained from the Aleman Ranch location (No. 23). Silicified wood and some fossil bone are found on the northeast side of the Mud Springs Mountains (No. 22) of the same county.

SMITHSONITE

Pure smithsonite, a zinc carbonate, is colorless and uniteresting with no gem stone value. However, when small amounts of zinc are replaced by copper it becomes a translucent apple-green to dark-green to blue semiprecious gem stone known as herrerite. In 1907 large quantities of a new green gem variety of smithsonite were found in various mines of the Magdalena district (No. 26) in Socorro County (Sterrett, 1908, p. 795). The most productive deposit was at the Kelly mine in a zinc vein in a cavity several feet wide and about 25 feet long. Here the green smithsonite lined the cavity in layers up to 2 inches thick yielding hundreds of pounds of excellent material that was cut and sold as cabachons (Sinkankas, 1959, p. 531). Accordingly to Northrop (1959, p. 475) collectors have so thoroughly combed the dumps in the district that extremely little herrerite of good color can be found today. Handsome specimens of herrerite from the Magdalena district are displayed in nearly every museum collection in the United States. Small amounts of herrerite have been reported to occur at the Stevenson-Bennett mine (No. 27) in the Organ district of Dona Ana County (Alfredo, 1952, p. 469).

SPURRITE

Spurrite, a combined silicate and carbonate of lime, is a rare mineral occurring only in Ireland, Mexico, California, and New Mexico. The only known New Mexico deposit was identified from the Tres Hermanas Mountains in 1928, where it occurs in a limestone xenolith in quartz monzonite on the east slope of South Sister Peak (No. 28) in Luna County (Griswold, 1961, p. 147). It is present as a band 20

feet long and up to 5 feet wide near the contact of intrusive rock with the limestone. This limestone covers several acres and is highly metamorphosed. Other bands of spurrite may be present but heavy talus cover has made thorough examination impossible. The New Mexico spurrite is pale gray with a delicate purple tinge. Talmage and Wootton (1937, p. 152) describe it as "compact and massive, can be cut and worked rather readily, and takes a fairly good polish." The spurrite from New Mexico is valued both as a rare collector's item and as an ornamental stone. Ash trays, book ends, pen stands, and paper weights have been fashioned from it on a purely experimental basis. This deposit has never been commercially exploited.

STAUROLITE

Staurolite, an iron aluminum silicate, has always been extremely popular due to its distinctive habit of growing twin crystals in the form of a cross. It is not essentially a gem material for its color is generally an unattractive dull reddish brown, and it is abundant throughout the United States and New Mexico. Staurolite, popularly called fairy cross, is one of the few minerals worn as jewelry in its natural state. Amulets, bracelets, earrings, and other ornamental jewelry have been sold as good luck charms and as curios. The most abundant cross occurs as two crystals that form approximately 60° angles, whereas the less common but more popular cross is formed of crystals at right angles. Staurolite has long been known in the New Mexico Precambrian schists. Eastern lapidaries were using Santa Fe staurolites as early as 1891. The most extensive deposit is in the schist and quartzite which crop out for many miles between Velarde and Pilar in the Glenwoody, Hondo Canyon, and Picuris districts (No. 29) of Taos County. Wherever the schist has been weathered crosses may be found. Staurolite is also common in the schists of the Manzano Mountains (No. 30) of Torrance County. Branson (1956, p. 135) says that staurolite deposits will never be depleted by collectors. The staurolite currently on the surface could supply all demand for years to come and each year more is weathered out.

TOPAZ

Topaz, an aluminum fluorsilicate, occurs as hard, transparent to translucent crystals with a wide range of color. Small topaz crystals can occasionally be found in ant hills throughout New Mexico (Talmage and Wootton, 1937, p. 86), but none are of gem size or quality. Clear colorless crystals up to an inch in length occur in gas cavities in rhyolite at the western base of Round or Maverick Mountain (No. 31) in the Taylor Creek district of Sierra County (Northrop, 1959, p. 512). "Massive nodules and giant crystals" of topaz were shipped in several carloads from the Organ Mountains (No. 27), Dona Ana County before 1957 (Northrop, 1959, p. 512).

TURQUOISE

Turquoise is an amorphous basic hydrous phosphate of copper and aluminum. Its color ranges from white through shades of green and blue. The value of turquoise is determined mainly by the color, sky

blue being the most highly prized, and waxy luster. The turquoise in New Mexico has generally been deposited as veinlets, seams, and nodules in monzonite porphyry. Gem quality is rarely found more than 100 feet below the surface. The principal deposits, in order of modern discovery, are in the Cerrillos Hills (No. 32) of Santa Fe County, the Burro Mountains (No. 33) and Little Hatchet Mountains (No. 34) of Grant County, and the Jarilla Mountains (No. 35) of Otero County.

Turquoise has been mined extensively but intermittently in New Mexico for the last 1,200 years. Numerous and varying estimates of modern production have been made. Pogue (1915, p. 52) says that the production from 1890 to 1915 probably exceeded $5 million while Northrop (1959, p. 528) estimates that the production from the Cerrillos and Burro Mountain districts alone may have reached $14 million. Since 1915 sporadic development and mining have produced a small amount, mainly of turquoise matrix. The known turquoise deposits of New Mexico have been largely exhausted. Indians often search old mine dumps for material, but the main source at present is Nevada.

The turquoise deposits of the Cerrillos Hills are the most important in the United States "from the point of view of history and past production" (Pogue, 1915, p. 52). Here the most, extensive prehistoric mining took place, particularly on Mount Chalchihuitl and Turquoise Hill. Every site that has been mined in modern times, as with all New Mexico deposits, had been previously worked by the ancient Indians. Some of the best sky-blue turquoise in the world has been mined from these deposits. The Tiffany mine produced the highest quality, valued at approximately $2 million. Deposits in the Burro Mountains were worked from about 1891 to 1914 and produced turquoise of excellent quality similar to that of Cerrillos. The Azure mine was the leading producer of the finest sky-blue turquoise, mainly from the Elizabeth Pocket, which measured 40 by 50 feet (Zalinski, 1907, p. 475). It is said to have produced between $2 and $4 million by 1914, with one nugget of 1,500 carats. The deposits in the Little Hatchet Mountains were developed between 1885 and 1888, and again around 1892 with little result. In 1908 extensive mining began, but it lasted only a few years. Fine sky-blue material was produced from a number of claims. In the Jarilla Mountains, Otero County, old Indian workings were discovered in 1892. A small amount of mining, mainly around 1898, produced some fine blue turquoise from within 40 feet of the surface (Jones, 1904, p. 277). Unfortunately its color faded after exposure to the atmosphere due to the evaporation of water.

GEM PRODUCTION

Although gem material production has steadily increased since World War II, it will continue to be a minor element of the mineral economy of New Mexico. The total gem material production in 1962 was only 0.007 percent of the total State mineral production. Resource figures are not available, but it is evident that New Mexico has large resources of many semiprecious gem materials, particularly of the quartz family. New Mexico will long provide its amateur collectors with gem materials. Further exploration in the mountainous area of the State will undoubtedly uncover numerous unknown deposits.

OPTICAL CALCITE

(By F. E. Kottlowski, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mex.)

Optical calcite is pure Iceland spar, the transparent crystal variety of calcite, $CaCO_3$. Commercial crystals must be colorless, transparent, and without cracks, twinning, inclusions, or other flaws. Optical-grade calcite is used in polarizing microscopes, polariscopes, colorimeters, saccharimeters, and other similar optical devices that use polarized light. Some has been used in special gun sights.

As noted by Fries (1948), optical calcite can occur in any type of rock and in rocks of Precambrian to Recent age. However, most deposits are in well-consolidated, andesitic to basaltic volcanic rocks of late Tertiary to Quaternary age. Optical calcite is believed to be precipitated in vents of hot springs and occurs in open fractures, fault fissures, or in breccia pipes.

Prior to World War II, less than 200 pounds of optical calcite were used in the United States annually. During 1943 and 1944 suboptical calcite was used extensively in gun sights, and production was about 10,000 pounds per year. After 1944, consumption dropped sharply and only about 100 pounds were being used annually in the early 1960's. The synthetic material polaroid has been substituted in many optical instruments that previously required calcite.

High quality Iceland spar has been mined in many places in the world. Most individual deposits are too small to support a mining operation for more than a few years. Since the late 1930's, most of the Nation's requirements have been supplied by mines in the states of Sonora and Chihuahua in northern Mexico, and sporadically from deposits in Montana, California, and New Mexico. No production or consumption statistics are available. Major optical companies maintain stocks of optical calcite for their own use. Prices are subject to negotiation; the best crystals may bring as much as $50 per pound (Waesche, 1960).

One of the most productive deposits in the United States was worked near Dixon in Taos County, N. Mex., just before World War II (Johnson, 1940; Kelley, 1940). This was in the Copper Mountain mining district on the Iceberg claim in sec. 31, T. 23 N., R. 11 E. about 300 feet southwest of the Harding pegmatite mine (No. 6, fig. 55) . Mining was first done in 1939 ; about 850 pounds of optical-grade calcite were mined, trimmed, and shipped, mainly to Bausch & Lomb Optical Co. The largest piece mined weighed 5 pounds 8 ounces. Others of the large calcite crystals are estimated to have weighed as much as 40 tons.

The Iceland spar occurred as a lenticular, pipe-like body in Precambrian amphibolite schist and quartzite (Schilling, 1960, p. 101—102) . The ore body was about 30 feet long in a northeast-southwest direction at the surface, had a maximum width of 9 feet, and dipped 70° southeast with a steep pitch to the northeast. The walls of the calcite body are brecciated and altered to depths of 1 to 3 feet. No euhedral calcite was found ; the main body was anhedral calcite. Three types of calcite occurred (1) white calcite, (2) banded pink calcite, and (3) clear, colorless calcite containing the optical-grade Iceland spar. Much of the clear, colorless calcite was not of optical grade because it was twinned. The calcite is believed to have been

deposited by hydrothermal solutions that filled openings and partly replaced breccia fragments in a previously formed breccia pipe.

Considering the extent of late Tertiary and Quaternary volcanic activity in New Mexico and the large regions covered by these upper Cenozoic volcanic rocks, it seems likely that future geologic exploration will find other deposits of optical calcite in the State.

PEGMATITE MINERALS

(By F. G. Lesure, U.S. Geological Survey, Washington, D.C.)

The chief pegmatite minerals that have been mined in New Mexico are mica, beryl, lithium minerals, and niobium-tantalum minerals. Large amounts of feldspar and quartz are present but have not been mined extensively. Other minor minerals found in the pegmatites but of no present economic importance include garnet, biotite, monazite, bismutite, samarskite, fluorite, magnetite, ilmenite, apatite, tourmaline, and various sulfides. The value of pegmatite minerals produced in New Mexico since modern mining began in 1870 is estimated to be nearly $1,500,000. Nearly two-thirds of this value has been from mica mined in the Petaca and Ojo Caliente districts of Rio Arriba County, and much of the remainder was from beryl, lithium minerals, and niobium-tantalum minerals produced from the Harding mine in Taos County. Minor production has come from San Miguel, Santa Fe, and Mora Counties. Pegmatites have been prospected or are known to occur in several other counties.

Pegmatites in New Mexico are mostly restricted to areas of metamorphic and igneous rock generally considered to be of Precambrian age (fig. 55). Pegmatites in a Tertiary quartz monzonite (Dunham, 1935, p. 111-116) and an unusual type of pegmatite in Teritary volcanic rock (Kelley and Branson, 1947) are not believed to be of economic importance.

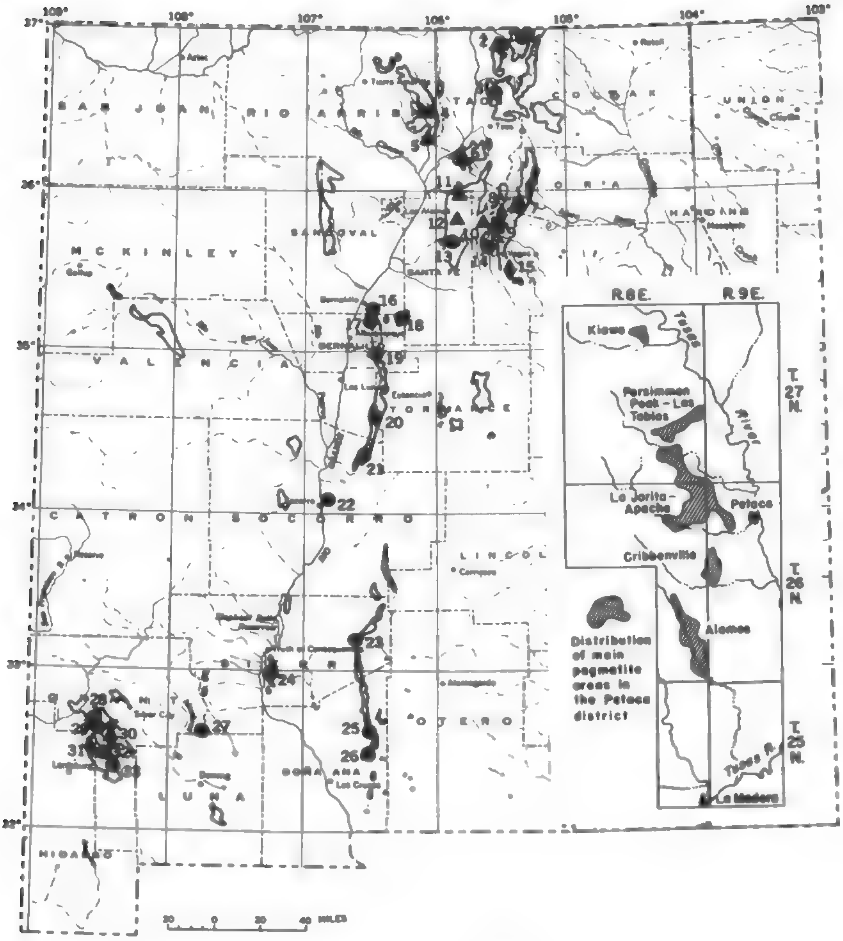
In this chapter emphasis is placed on deposits of mica,. lithium minerals, and feldspar. Beryl and minerals containing niobium-tantalum, rare earths, and thorium are discussed in other chapters of this report.

PEGMATITES

Pegmatites are coarsely crystalline igneous rocks generally found as lenticular or tabular bodies in metamorphic rocks or associated with large granitic intrusions. Individual mineral grains range in size from an inch or less to many feet, and large variation in grain size within a single pegmatite body is common. Pegmatites are composed mostly of feldspar, quartz, and mica. The many rare and unusual accessory minerals found in some pegmatites make them favorite collecting sites for mineralogists and rockhounds.

In many pegmatites the minerals are more or less evenly distributed throughout, but in others the minerals are segregated into zones. These zones can sometimes be selectively mined by hand sorting to recover the desired minerals and are, therefore, important economically.

In general, zones are successive shells, complete or incomplete that reflect the shape or structure of the pegmatite body as a whole, and



EXPLANATION

Precambrian rocks

Feldspar-rich pegmatites May contain concentrations of other minerals

Muscovite-bearing pegmatites

Beryllium-lithium-columbium-tantalum-bearing pegmatites

Pegmatite areas

1. Costilla massif area
2. Cedros prospect
3. Taos Range near Rio Hondo
4. Petaca district
5. Ojo Caliente district
6. Harding mine and Picuris Range
7. Mora area
8. Pidlite mine
9. Elk Mountain area
10. Pecos River—Willow Creek area
11. Cordova district
12. Aspen Ranch area
13. Santa Fe area
14. Guy-stern deposit
15. Old Priest deposit
16. Northern Sandia Mountains
17. Sandia Mountains
18. Monte Largo
19. Manzano Mountains
20. South Manzano Mountains
21. Los Pinos Mountains
22. Joyita Hills
23. Rhodes Canyon, San Andres Mountains
24. Caballo Mountains
25. Ash Canyon, San Andres Mountains
26. Organ Mountains
27. Northern Cooks Range
28. Northern Big Burro Mountains
29. Spar Hill—Long Lost Brother area
30. White Signal district
31. Gold Hill area
32. Bluebird area
33. Continental—American area

FIGURE 55.—Pegmatites in New Mexico.

where best developed, they are concentric about an innermost zone or core (Cameron and others, 1949, p. 14). According to accepted terminology the zones from the outermost to the core are called border zone, wall zone, and intermediate zones. In some pegmatites the border zone is a selvage only a fraction of an inch thick, but in others it is several feet thick. Within the border zone is a wall zone that ranges in thickness from a foot or less to several tens of feet and consists mostly of coarse microcline and quartz with minor muscovite, garnet, fluorite, and beryl. Inside the wall zone may be one or more intermediate zones that are rarely complete shells. Many are hoodlike units with a wide range in thickness and composition. Most cores are massive quartz, but a few consist of coarse-grained microcline-quartz pegmatite.

The structure of some zoned pegmatites is complicated by the presence of fracture fillings, which are more or less tabular masses of later minerals that cut previously formed zones, and replacement bodies. Some of the replacement is controlled by preexisting fractures in the pegmatite and some is controlled by the zonal structure (Jahns, 1951, p. 53-54).

MICA

The principal mica minerals are muscovite (white mica), biotite (black mica), and phlogopite (amber mica). All have a perfect basal cleavage and form crystals that can be split into thin sheets having various degrees of transparency, toughness, flexibility, and elasticity. The micas are common minerals, but only muscovite is mined in the United States.

Two types of mica are sold : sheet mica, which must be relatively flat, free from most defects, and large enough to be cut in pieces 1 inch square or larger; and scrap mica, which includes all mica that does not meet sheet mica specifications and which is generally ground to a powder. Small sheets of untrimmed mica of poorer quality that can be punched or trimmed into disks 1 inch or larger in diameter are classified as punch mica and are included in the general term sheet mica. Sheet muscovite is an important insulating material in the electronic and electrical industries. The principal uses of scrap mica are in roofing, wallpaper, rubber, and paint.

Sheet-quality muscovite is obtained from the large crystals scattered throughout unzoned pegmatites or concentrated in certain units of zoned pegmatites. The value of sheet mica depends on the color, size, structure, and quality of the natural crystals. Reddish-brown or ruby mica brings a higher price than green mica, which is the predominant type found in New Mexico. Mica that is clear and flat is more valuable than mica that is stained (contains inclusiOns of foreign matter between the sheets) or is bent and cracked. Much of the New Mexico mica contains crystal imperfections and structural defects or is too small and is therefore classed as scrap mica. Only a small percentage of the mica, however, is stained. The manner in which the crystals are mined and the care and skill of preparation are also important factors affecting the value.

The best published reference on the details of the preparation and classification of mica and trade practices of the industry is by Chand Mull Rajgarhia (1951). Excellent references written in the United States are by Skow (1962), Montague (1960), Jahns and Lancaster

(1950), and Wierum and others (1938). Jahns (1946, p. 76-86) gives a short description of the properties, classification, and preparation of mica with specific references to deposits in New Mexico.

The discontinuous nature of most mica concentrations, the great range of quality of material, the expense of mining, and the large amount of hand labor needed for preparation generally limit sheet mica mining to periods of high prices. Since the end of the Government purchasing program in June 1962, little sheet mica has been mined in the United States. Most of the recent production has been from North Carolina, New Hampshire, and South Dakota. Table 38 shows the production of sheet and punch mica in New Mexico from 1921 to 1963; it amounts to about 0.5 percent of the U.S. total for the period.

TABLE 38.—*Production of sheet and punch mica in New Mexico, 1921–63*

Year	Quantity (pounds)	Value	Year	Quantity (pounds)	Value
1921–22	---	---	1949	---	---
1923	30,300	8,489	1950	(1)	(1)
1924	29,803	6,585	1951–53	---	---
1925	34,486	7,531	1954	2,064	13,845
1926	46,104	5,824	1955	9,431	64,930
1927	(1)	(1)	1956	6,247	52,566
1928	11,822	2,266	1957	2,134	55,645
1929	4,550	1,368	1958	1,791	18,397
1930–41	(1)	(1)	1959	247	1,598
1942	11,380	3,000	1960	5	4
1943	6,699	20,000	1961	---	---
1944	3,347	9,000	1962	(1)	(1)
1945	(1)	(1)	1963	---	---
1946–47	---	---			
1948	(1)	(1)	Total [2]	222,097	[2] 250,000

[1] Confidential figure; included in total.
[2] Includes confidential figures indicated by footnote 1.

Source: U.S. Department of Interior, Bureau of Mines.

Many pegmatite deposits yield only scrap mica, and a large amount of scrap is produced during the mining, trimming, and fabricating of sheet mica. Scrap mica is also recovered from mica schist and as a byproduct from the mining of feldspar and clay. Most of the mica mined in the United States is scrap mica. Table 39 shows the production of scrap mica in New Mexico since 1899, which probably represents about 1.5 percent of the U.S. total.

TABLE 39.—*Production of scrap mica in New Mexico, 1899–1963*

Year	Quantity (pounds)	Value	Year	Quantity (pounds)	Value
1899	123	$3,500	1938	770	$8,000
1900	258	2,500	1939–42	(2)	(2)
1901	146	1,500	1943	393	7,000
1902	1	40	1944	816	15,000
1903–06	(1)	(1)	1945	491	9,000
1907	-----	-----	1946	-----	-----
1908	(1)	(1)	1947	48	1,249
1909	-----	-----	1948	-----	-----
1910	25	(1)	1949	40	1,300
1911–17	-----	-----	1950	354	10,820
1918–22	(2)	(2)	1951	1,500	45,000
1923	898	16,417	1952	700	28,000
1924	178	3,248	1953	-----	-----
1925	920	14,580	1954	[3] 19	(1)
1926	988	16,683	1955	[3] 189	2,475
1927	776	12,741	1956	[3] 851	22,213
1928	1,328	28,426	1957	[3] 1,372	46,865
1929	420	8,210	1958	[3] 835	24,466
1930	768	12,044	1959	[3] 217	6,562
1931	(2)	(2)	1960	235	6,780
1932	537	8,100	1961	1,800	52,200
1933	428	4,000	1962	5,731	140,000
1934	602	8,000	1963 [4]	6,864	184,000
1935	1,820	22,000			
1936–37	(2)	(2)	Total	[5] 36,723	[5] 756,300

[1] Information not available.
[2] Confidential figure; included in total.
[3] Includes scrap mica from hand-cobbed mica sold to General Services Administration.
[4] Preliminary figures.
[5] Includes confidential figures indicated by footnote 2.

Sources: U.S. Department of Interior, Bureau of Mines; New Mexico State Inspector of Mines.

Mica mining began in New Mexico as early as the 18th century when mica from the Petaca district, Rio Arriba County, was used in windows in Santa Fe (Just, 1937, p. 58; Northrop, 1959, p. 18). Interest in the mica deposits was renewed in 1870 when mining began to supply mica for stove windows. According to Just (1937, p. 59), the old mining settlement of Cribbensville, which was the center of this mining, was named after the maker of a popular brand of stove. After 1900, mining in the Petaca district was greatly expanded and several deposits were opened for scrap mica. Important periods of production include 1923-30, 1935-40, and 1942 _41 during the Government purchase program of World War II. A second Government purchase program from 1952 to 1962 increased production of sheet mica temporarily (table 38). Since 1961 the production of scrap mica, however, has increased each year (table 39). In 1961 three scrap mica plants were operated : the Clute Corp. mica grinding mill at Pojoaque, Santa Fe County, the Los Compadres Mica Co. grinding mill at Ojo Caliente, Taos County, and the Alaska International Corp. mobile plant at the Joseph mine, Rio Arriba County (Hahn, 1962). Resources of sheet mica in New Mexico are difficult to determine because available data are unsatisfactory; reserves of scrap mica probably are large.

The selling price of mica can range from only a few cents per pound for punch or scrap to many dollars a pound for large sheets of the best quality. In 1958 the price schedule under the U.S. Government purchase program for sheet mica of superior quality (termed "good stained or better") ranged from $17.50 per pound for the smallest sizes to $70 per pound for the large sizes. Prices in 1958 for India mica of similar quality ranged from $2.50 to $37 per pound (Montague, 1960, table 8). In 1963 prices for sheet mica as quoted in the

Engineering and Mining Journal Metals and Markets ranged from \$9.07 a pound for sheets 11/2 inches across to \$8 a pound for sheets 8 inches or more across. Scrap mica is valued at the mine at \$20 to \$30 per short ton. Most of the buyers of mica are in the Eastern United States.

FELDSPAR

Feldspar is the general name for a group of aluminum silicate minerals that contain varying amounts of potassium, sodium, or calcium and constitute nearly 60 percent of igneous rocks. The principal potassium feldspars are orthoclase and microcline, which have the same chemical composition ($KAlSi_3O_8$) but different crystal forms. The sodium-calcium feldspars, called plagioclase, form a complete series of minerals that range in all proportions from pure $NaAlSi_3O_8$ (albite) to pure $CaAl_2Si_2O_8$ (anorthite). Most orthoclase and microcline contain 10 to 25 percent $NaAlSi_3O_8$ and plagioclase generally contains 5 to 15 percent $KAlSi_3O_8$. Intergrowths of orthoclase or microcline with albite are called perthite, a common pegmatite mineral. Cleavelandite, a platy form of albite, is common in many pegmatites in New Mexico.

The potassium feldspars and the more soda-rich varieties of plagioclase are the types generally mined. Until recently much of the feldspar produced was perthite, which is commonly concentrated as very large crystals in certain zones in pegmatite bodies. Today finer grained pegmatite is mined in bulk and a mixture of potassium and sodium feldspars is recovered by milling and flotation.

Production of feldspar from New Mexico is not recorded, although some has been recovered and stockpiled during the course of mining for other pegmatite minerals. Substantial resources of high-grade potassium feldspar are available in New Mexico, especially in the Petaca district (Jahns, 1946, p. 264), but the long distance to potential buyers makes feldspar mining unlikely until a local demand develops.

LITHIUM MINERALS

The chief lithium minerals obtained from pegmatites in the United States are spodumene, a lithium aluminum silicate that is the main source of lithium; lepidolite, a lithium mica that is used in glass and ceramics; and amblygonite, a lithium aluminum phosphate, for which there is only a sporadic market. More than 13,000 tons of lepidolite ore and several hundred tons of spodumene ore have been produced in New Mexico since 1920. Most of this production, which represents nearly 10 percent of the total U.S. production between 1920 and 1950, came from the Harding mine in Taos County. A small amount came from the Pidlite mine in Mora County. No production of lithium minerals in New Mexico has been recorded since 1950, and today most lithium minerals are mined from large deposits in North Carolina, Quebec, and Southern Rhodesia.

Prices of lithium minerals are based on quantity of lithia (Li_2O) in the ore and are negotiated directly between buyer and seller. Prices quoted per unit of Li_2O (a unit being 1 percent of 1 short ton or 20 pounds) ranged from \$11 to \$12 for spodumene and lepidolite ores in 1955 (Schreck, 1961, p. 56, 59).

Jahns (1953, p. 1098) estimated the amount of lepidolite and spodumene in the Pidlite mines to be 530 tons in 1947, but how much of this has been mined since then is not known. Other pegmatites with lithium minerals occur near the Pidlite mines and the area has not been completely prospected. Large quantities of lepidolite and spodumene probably still remain in the Harding pegmatite but no reserve data have been published.

Much of the lithium-bearing rock is low grade and some sort of milling and flotation process would be necessary to recover the lithium minerals. Recent beneficiation studies of pegmatite ores indicate several possible methods (Bhappu and Fuerstenau, 1964).

PEGMATITE DEPOSITS IN NEW MEXICO

Pegmatites are reported in many of the outcrop of metamorphic and igneous rock of Precambrian age in New Mexico, but the principal deposits are in Rio Arriba, Taos, San Miguel, and Mora Counties. Most of the important deposits have been described by Sterrett (1923, p. 158-165), Just (1937), Jahns (1946, 1951, and 1953), and Redmon (1961). References to pegmatites in the less known areas are generally vague and scattered in the literature. The major pegmatite districts are discussed in the following pages and miscellaneous deposits are listed on table 40.

TABLE 40.—*Miscellaneous pegmatites in New Mexico*

County	Locality	Location number (see figure 55)	References
Bernalillo	Sandia Mountains	17	Ellis, 1922, p. 24. Kelley, 1[illegible]. Northrop, 1959, p. 361.
Do.	Monte Largo	18	Kelly, 1963.
Do.	Manzano Mountains	19	Reiche, 1949, p. 1194.
Colfax	Western part of county		U.S. Inter-Agency Comm.
Dona Ana	Ash Canyon	25	Kottlowski and others, 1956, p. 5.
Do.	Organ Mountains	26	Dunham, 1935, pp. 33 and 111-116.
Sandoval	North Sandia Mountains	16	Kelly, 1963.
Santa Fe	Sangre de Cristo Mountains	13	Kottlowski, 1963, p. 233.
Sierra	Rhodes Canyon	23	Kottlowski and others, 1956, p. 5.
Do.	Caballo Mountains	24	Kelley and Silver, 1952, pp. 32-33.
Do.	Fra Cristobal Mountains		Harley, 1934, pp. 23-24.
Do.	Black Range		Do.
Socorro	Los Pinos	21	Stark and Dapples, 1946, p. 1140.
Do.	Joyita Hills	22	Herber, 1963, p. 181.
Do.	Little Burro Peak		Talmage and Wootton, 1937, p. 117.
Torrance and Valencia	South Manzano Mountains	20	Stark, 1956, p. 23.

Grant C aunty.—Pegmatite dikes ranging from a few inches to 50 feet or more in thickness are found in the Precambrian rocks along the west flank of the Big Burro Mountains (No. 28) north of the Redrock-Silver City road (Hewitt, 1959, pp. 73-76). Most of these are unzoned mixtures of quartz, microcline, minor plagioclase, and accessory muscovite and biotite. Garnet, magnetite, molybdenite, allanite, and opal are rare accessory minerals. One deposit on the ridge between Black Hawk and Saddle Rock Canyon contains stained muscovite in books as much as 5 inches across.

Perthite-rich pegmatite dikes ranging in length from less than 50 to more than 600 feet cut Precambrian granite near the Spar Hill (No. 29), Long Lost Brother (No. 29), Bluebird (No. 32), Continental (No. 33), and American (No. 33), fluorspar deposits in the southern part of the Burro Mountains (Gillerman, 1952, pp. 265, 279; 282, 286, and pls. 52, 53, 55, 57, 58). Pegmatite in the Gold Hill area (No. 31) contains euxenite and samarskite, and pegmatite at the High Noon No. 1 prospect in the White Signal district (No. 30) contains euxenite (Parker 1963). Coarse-grained quartz-microcline-biotite granite in the north end of the Cooks Range (No. 27) is cut by pegmatite (Elston, 1957, p. 4) .

Mora County.—Pegmatites are exposed in several areas of Precambrian rock in the eastern part of the Sangre de Cristo Range in western Mora County. Mica-bearing pegmatites near Mora have been known for many years and some early prospecting was done (Sterrett, 1923, pp. 158-159). Two deposits are reported to have yielded black- to brown-specked mica and others yielded clear mica. Most of the mica is reeved and tanglesheet.

A zoned pegmatite body 3,000 feet long and 120 feet wide, about a mile southwest of Mora (No. 7), has been mined for scrap mica (F. D. Everett, written communication, 1953). The pegmatite contains a wall zone of fine-grained orthoclase and quartz, 20 feet wide; an intermediate zone of perthite and mica, 20 feet wide; and a quartz core, 40 feet wide. The Great Western Mining Co. started a scrap operation in 1949 and continued work until 1952. The rock was mined, crushed, and screened, and the product trucked to Las Vegas for shipment to Buckeye, Ariz., for final grinding.

A small pegmatite in biotite schist, about 2 miles south of Mora (No. 7), consists dominantly of microcline and quartz but contains accessory albite, beryl, ilmenite, and tourmaline (L. A. Wright, written communication, 1943). Other pegmatites in the same area are chiefly microcline and quartz with a few accessory minerals.

Several lithium-bearing pegmatite dikes in Precambrian gneiss and schist are exposed in an area at least 2 miles long on the east slope of the Sangre de Cristo Range near the headwaters of Sparks and Maestas Creeks in Mora and San Miguel Counties (Jahns, 1953, p. 1081). One of the largest of these bodies was mined by the Hayden Mining Co. at the Pidlite mine (No. 8) in 1946-47. The pegmatite is a discoidal lens that contains a border zone of albite-quartz-muscovite-perthite pegmatites with accessory apatite, beryl, fluorite, spessartite, and tourmaline; a wall zone of coarse-grained perthite-quartz-albite-muscovite pegmatite; an intermediate zone of quartz-perthite; and a core of massive quartz. Cleavelandite, muscovite, and lepidolite occur in replacement bodies. The assemblage of minerals is similar to that at the Harding mine (Jahns, 1953, p. 1089). The area, which is heavily timbered and has a thick mantle of soil and vegetation, has not been completely prospected.

Rio Arriba County.—The mica deposits of the Petaca (No. 4) and Ojo Caliente (No. 5) districts in Rio Arriba County are the chief sources of sheet and scrap mica in New Mexico. The districts were studied by Just (1937) and Jahns (1946) and some of the mines were described briefly by Holmes (1899, p. 706-707), Sterrett (1923, p. 159-164), Holmquist (1947), and Wright (1948). The regional geology of part of the Petaca district has recently been mapped by

Barker (1958). The following summary is based mainly on the report by Jahns (1946) .

In the Petaca district an area of 60 square miles is underlain by Precambrian quartzite and quartz mica schist. A fine- to medium-grained granite intrudes these metamorphic rocks and pegmatite dikes cut both granite and metamorphic rocks. Jahns (1946, p. 23) recognized three general groups of pegmatite, each structurally distinct. The pegmatites in the granite are small, irregular, and discontinuous. They are commonly homogeneous, mineralogically simple, and in general have no commercial value. Pegmatites in the metamorphic rock are both concordant and discordant to the foliation. The concordant pegmatites are essentially homogeneous but a few are rich enough in places to have been mined for mica. The discordant bodies are cigar, trough-, lath-, or funnel-shaped; most are zoned and contain minable concentrations of mica or other minerals. The principal minerals are microcline, perthite, quartz, plagioclase, and muscovite. The chief accessory minerals, named in order of abundance, are garnet, green fluorite, columbite-tantalite, monazite, beryl, ilmenite, magnetite, bismutite, purple fluorite, samarskite, sulfides, uraninite, pink muscovite, apatite, lepidolite, and tourmaline.

According to Jahns (1946, p. 28-29) the mica-rich pegrnatites occur chiefly in five distinct groups : the Kiawa, Persimmon Peak-Las Tablas, La Jarita-Apache, Cribbenville, and Alamos. The Kiawa group in the northwest part of the district comprises four mines including the Kiawa (sec. 11, T. 27 N., R. 8 E.), where mining started in 1880. Production from the Kiawa mine up to the end of World War II amounted to 600 tons of scrap mica and more than 2,000 pounds of sheet mica. Large concentrations of sheet and scrap mica may remain in the Kiawa and large bodies of high-quality potassium feldspar are also present (Jahns, 1946, p. 115) .

The largest group, containing 30 or more mines and prospects, is the La Jarita-Apache group in the center of the Petaca district. The Apache mine (sec. 12, T. 26 N., R. 8 E.) has been worked intermittently for nearly a century, and has the largest production record of any mine in the Petaca district. About 85,000 pounds of sheet and 4,000 tons of scrap mica were produced up to 1940 (Jahns, 1946, p. 165). The property was worked intermittently from 1954 to 1962, during the recent Government purchase program.

The Cribbenville group includes the older mines in the district. The Fridlund (sec. 18, T. 26 N., R. 8 E.), Capitan (sec. 13, T. 26 N., R. 8 E.), Cribbenville (sec. 18, T. 26 N., R. 9 E.) and Nambe (sec. 18, T. 26 N., R. 9 E.) mines have produced mainly scrap, but also some i sheet mica. The largest mine in the group is the North Cribbenville (sec. 10, T. 26 N., R. 9 E.) from which at least 40,000 pounds of stove mica, 20,000 pounds of clear sheet, and 1,500 tons of scrap mica have been mined (Jahns, 1946, p. 193) .

The Alamos group includes several large mines at the south end of the district. The White or Lyons deposit (sec. 25, T. 26 N., R. 8 E.) has produced more than 2,000 pounds of sheet and several hundred tons of scrap mica, and, according to Jahns, (1946, p. 223) contains some additional mica and an appreciable amount of feldspar. The Globe mine (sec. 36, T. 26 N., R. 8 E.) yielded 20,000 pounds of sheet mica, 5,000 tons of scrap mica, and 5,000 pounds of columbite between

1900 and 1945 (Jahns, 1946, p. 233), and was worked again from 1954 to 1959. A few other mines not included in the five groups are also described by Jahns (1946, p. 245-260) .

In assessing the future possibilities of the district, Jahns (1946, p. 261-264) pointed out that detailed geologic studies have shown the mica shoots to be irregular in detail but consistent in position and orientation with respect to the shape and Structure of the pegmatite. Other minerals such as monazite, tantalite-columbite, samarskite, and beryl are distinctly accessory and should not be used as a basis for exploration but could be recovered as a byproduct of mica mining. The substantial amounts of feldspar that are present may become an important resource. Many of the dumps contain large amounts of scrap mica and some have been used as mill feed for Los Compadres Mica Co. mill at Ojo Caliente (Hahn, 1962, p. 716).

The Ojo Caliente district (No. 5) includes more than 20 mines and prospects in an area of 4 square miles about 1/2 miles north of the village of Ojo Caliente and just west of the Caliente River (Jahns, 1946, p. 265). The pegmatites are tabular bodies 25 to 750 feet long and 3 to 65 feet thick. Most of them are zoned sills in amphibole schist. Garnet, fluorite, and beryl are widespread accessory minerals in the wall zones. Columbite and monazite are locally abundant in brick-red albite, and samarskite, bismutite, and sulfides are common in quartz-albite pegmatite.

The largest mine in the group, the Joseph (sec. 11, T. 24 N., R. 8 E.) produced several thousand tons of scrap mica prior to 1932. The mine was being worked by Alaska International Corp. in 1961-62, and the mica processed in a mobile processing and treatment plant (Hahn, 1962, p. 728).

San Miguel County.—Several areas of Precambrian rocks contain pegmaitites in the southern part of the Sangre de Cristo Range in the northwest corner of San Miguel County (Jahns, 1946, p. 275). The Elk Mountain district (No. 9) covers an area of 30 square miles near the crest of the range as well as smaller areas along the Pecos River, Willow Creek, and west-flowing tributaries west of the range crest (No. 10). The pegmatite bodies generally occur in schist and range from sinuous dikes to thick pods. Garnet, fluorite, and columbite are common accessory minerals; tourmaline and beryl are rare. Pegmatites near the Pecos River and Elk Mountain contain abundant green to brownish-green muscovite. The books are hard, clear, and flat but generally ruled and cracked. Pegmatites in the rest of the area generally contain stained mica of poor structural quality that is scrap grade. Anderson (1956, p. 141) reports pegmatites with molybdenite and fluorite near Hermit Peak, east of Elk Mountain.

The Elk Mountain, or Kept Man, deposit (No. 9), was worked extensively during World War II and was explored by the U.S. Bureau of Mines in 1944 (Holmquist, 1946). The Betty Jean deposit (No. 10) along the Pecos River 2.5 miles northeast of Terrero was mined in 1943 in an open cut. The pegmatite is over 500 feet long and 15 to 28 feet thick.

Southeast of the Elk Mountain district the pegmatites contain local concentrations of rare minerals such as monazite, columbite, uraninite, samarskite, hatchettolite, euxenite, fergusonite, and gadolinite. Mica in these deposits is generally of scrap quality and much is tangle sheet, wedge shaped, bent, broken, reeved, and stained. The Guy No.

1 deposit (No. 9) in SW1/4 sec. 36, T. 18 N., R. 13 E. is on the ridge between Burro and Gallinas Canyons. Production from small-scale operations prior to and during World War II included several tons of scrap mica and more than 500 pounds of tantalum, uranium, and rare earth minerals (Jahns, 1946, pp. 281-283). The Old Priest deposit (No. 15) is about 6 miles north of Ribera. According to Anderson (1956, p. 141) mica from the deposit was used by early Spanish settlers for windows. There was a moderate production of scrap mica before World War II and a small production of mica, beryl, columbite-tantalite, and monazite in recent years. The deposit is exposed in an area 400 feet long and 90 feet wide. According to Anderson (1956, p. 141) other pegmatites in the vicinity are rich in mica and contain some beryl, and pegmatite dikes rich in mica have been prospected a few miles west of Tecolote village.

The Guy-Stearn deposit (No. 14) is near the head of a tributary to Manzanares Creek (sec. 30, T. 17 N., R. 13 E.) between Cow Creek on the west and Bull Creek on the east. The deposit is a large pegmatite dike, 30 to 80 feet thick, composed of a coarse-grained quartz core with minor cleavelandite, and a narrow microcline-quartz-oligoclase-muscovite wall zone. Garnet, monazite, bismutite, columbite, gadolinite and apatite are accessory minerals (R. H. Jahns, written communication, 1943).

Santa Fe County.—A large pegmatite dike swarm is found in the Cordova district (No. 11) in northeastern Santa Fe County. The BAT claims in secs. 1-3, T. 20 N., R. 10 E. contain 15 or more pegmatite dikes that range from small lenses 5 feet wide and tens of feet long to large masses several hundred feet long (D. H. Richter, written communication, 1957). Most of the pegmatites are medium-grained mixtures of quartz, perthitic microcline, plagioclase, and muscovite. Accessory minerals include tourmaline, garnet, ilmenite, and vermiculite. Large books of muscovite occur in coarse-grained pegmatite at the BAT 2 claim in a dike 10 feet wide and 160 feet long. The mica is in books 6 inches across and is reeved and stained.

The Rocking Chair claims in the Cordova district (No. 11) contain several pegmatite dikes as much as 900 feet long and 80 to 100 feet wide (D. R. MacLaren, written communication, 1955). Most of the pegmatites contain quartz, microcline, plagioclase, and muscovite. A few contain accessory beryl and columbite-tantalite. The Rocking Chair No. 2 claim has a pegmatite with a fine-grained quartz-albite-microcline-muscovite wall zone and a microcline-quartz core. The mica is small, stained, and reeved. Several tons of scrap mica and less than 1,000 pounds of beryl are reported to have come from a large prospect pit (W. L. Emerick, written communication, 1958).

The Santa Rita beryl prospect (sec. 7, T. 20 N., R. 11 E.) just to the south of the Rocking Chair claims was prospected for mica and beryl during World War II. An irregular quartz-feldspar-muscovite pegmatite more than 100 feet long contains muscovite in books as much as 10 inches across and scattered crystals of beryl (C. A. Anderson, written communication, 1943). Other pegmatites occur on the Lucky Star and Tony Jo claims (No. 12) near Aspen Ranch to the south. Some scrap mica has been produced from pegmatites in the area.

Taos County.—The chief pegmatite deposit in Taos County and the

largest single deposit in New Mexico is at the famous Harding mine (6), which has produced large amounts of lithium minerals, tantalum minerals, and beryl. The deposit was discovered in 1910 but mining did not start until 1920 when the Mineral Mining & Milling Co. began producing lepidolite and shipping it to Wheeling, W. Va., for use in the glass industry. The Embudo Milling Co. took over the property in 1927, the Pacific Minerals Co., Inc., in 1928, and the Embudo Milling Co. again in 1930. Operations ceased in 1930 after the production of more than 12,000 tons of lepidolite ore averaging 3.5 percent L1$_2$0 (Schilling, 1960, p. 98). A description of this early mining is given by Roos (1926).

In 1942 Arthur Montgomery acquired the property and began mining microlite, a tantalum mineral. Some beryl and spodumene were also recovered by hand sorting during the war years. In 1943 and again in 1945 the U.S. Bureau of Mines drilled a total of 46 diamond drill holes down dip from the quarry and outlined a large deposit of microlite and spodumene (Soule, 1946; Berliner, 1949). The mine was mapped and studied by the U.S. Geological Survey (Jahns, 1951), and the regional geology and mineralogy of the pegmatite were studied by Montgomery (1950, 1951, 1953). From 1945 to 1947 J. A. Wood was in charge of microlite mining, and a 10-ton mill was built on the Rio Grande at Rinconado (Wood, 1946). Some lepidolite and spodumene ore were recovered by the New Mexico Mining & Concentrating Co. in 1950-51 and from 1950 to 1959 Montgomery and Griego mined beryl in the upper part of the pegmatite (Schilling, 1960, p. 100). Mining has been carried on both in a quarry and underground. Lithium minerals have been produced mainly by quarry methods, beryl has been mined underground from adits and crosscuts, and tantalum ore (microlite and tantalite-columbite) has been mined both underground and in the quarry.

The pegmatite is a tabular body that dips gently to the southwest, is more than 300 feet wide, extends 3,000 feet down dip, and averages 50 to 55 feet thick. It is complexly zoned and contains a quartz-microcline-muscovite-albite-beryl wall zone; a zone of massive quartz below the hanging-wall zone which grades downward into a thick zone of quartz and spodumene that contains some beryl ; and a core of coarse-grained spodumene, microcline, and quartz with varying quantities of albite, muscovite, lepidolite, and tantalum minerals. Although the pegmatite may have been symmetrically zoned, many of the original lithologic units in the lower half have been obscured by the formation of albite and mica replacement units (Jahns, 1951, p. 52-53). Reserves of lithium minerals, beryl, and tantalum minerals are probably large.

Other pegmatites crop out near the Harding mine and elsewhere in the Picuris Range (Just, 1937, p. 26; Montgomery, 1953, p. 46-48), but consist chiefly of perthitic microcline, quartz, and mica. Accessory minerals include beryl, columbite-tantalite, and cleavelandite. One small deposit about a mile up Fletcher Canyon south of Pilar contains fairly abundant lepidolite (Montgomery, 1953, p. 47) .

The Cedros prospect (No. 2) in the northern Taos Range is on a ridge west of the south fork of the Rito de los Cedros, 5 miles south-southeast of Costilla (Schilling, 1960, p. 28-29 ; McKinlay, 1956, p. 11, 27) . A pit and trench expose a pegmatite dike in Precambrian

quartz-mica schist. The dike is 5 feet thick and over 1,000 feet long. It contains a border zone as much as 1 foot thick of graphic granite and muscovite; a wall zone 2 feet thick of intergrown white albite, quartz, and muscovite, and accessory garnet, beryl, and chrysoberyl; and a discontinuous core of white quartz. The mica is abundant but mostly scrap quality. Books as large as 3 inches occur in the border zone.

There is a swarm of pegmatite dikes in an area 5 to 6 miles long near the top of the Costilla massif (No. 1), and there are others northeast of the Cedros prospect, north of the mouth of Comanche Creek and in the Taos Range near the Rio Hondo (No. 3) (McKinlay, 1956, p. 11; 1957, p. '7). The pegmatites range from stringers 3 inches thick to large lenses 50 feet or more wide and over 2,000 feet long. They are commonly zoned and contain a quartz core and albite-quartz wall zone. Magnetite and garnet are common accessory minerals in the border or wall zone, and black tourmaline is present in a dike north of Latir Peak (McKinlay, 1956, p. 11).

NIOBIUM AND TANTALUM

(By **R.** L. Parker, U.S. Geological Survey, Washington, D.C.)

Niobium (columbium) and tantalum are two refractory metals that have become increasingly important in electronic, nuclear, chemical, and high temperature metallurgical applications. Both have important uses in the manufacture of vacuum tube elements, cryotrons, corrosion-resistant vessels and other laboratory ware, high temperature nonferrous alloys, and special stainless steels. Niobium is used as a cladding element for nuclear fuel. Tantalum has special application in capacitors, rectifiers, surgical implants, and as a catalyst in the manufacture of butadiene rubber (Miller, 1959 1959; Barton, 1962).

The United States is the world's largest consumer of niobium and tantalum, but it is a small producer (Barton, 1962) . Except for the period 1956-59, domestic production of these metals constituted a minute fraction of the domestic consumption (fig. 56). In 1958 domestic production, which came principally from Idaho placers, reached an alltime high of nearly 12 percent of domestic consumption, but since 1959 domestic production has been negligible. New Mexico's total production of nearly 34,000 pounds of niobium-tantalum concentrates ranks it third among the States, with a little more than 2 percent of the National total. In 1962 imports of niobium and tantalum concentrates were about 6,234,000 pounds.

Niobium and tantalum commonly are found together in oxide minerals that also contain minor amounts of titanium, tungsten, iron, manganese, rare earths, uranium, thorium, sodium, and calcium. The most important ore minerals are : columbite-tantalite, (Fe, Mn) (Nb, Ta) $_2$0,; ; pyrochlore, NaCaNb$_2$06F ; microlite, (Na, Ca) 2Ta$_2$06 (0, OH, F) ; euxenite, (Y, Ca, Ce, U, Th) (Nb, Ta, ; samarskite, (Y, Er, Ce, U, Ca, Fe, Pb, Th) (Nb, Ta, Ti, Sni206; and fergusonite, (Y, Er, Ce, Fe) (Nb, Ta, Ti) 04. Niobium and tantalum are also contained in various amounts in the titanium minerals, sphene, rutile (ilmenorutile), and ilmenite (Pal ache, Berman, and Frondel, 1944).

Relatively, niobium is not a rare element in the earth's crust ; it is about as abundant as cobalt and more plentiful than lead. Tantalum

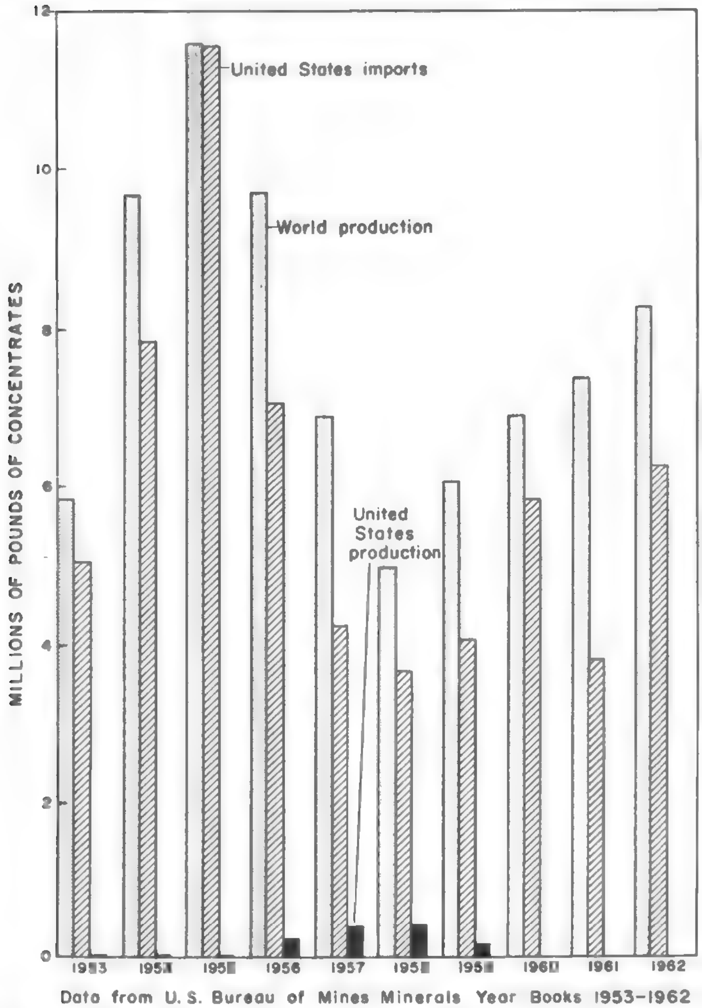


FIGURE 56.—World and U.S. production and U.S. imports of niobium and tantalum concentrates, 1953–62.

is much rarer than niobium, but still more abundant than antimony, silver, or gold. Compared with many other valuable elements whose crustal abundance is less than niobium or tantalum, deposits of niobium and particularly tantalum are scarce.

Niobium and tantalum deposits occur throughout the world in granitic rocks and pegmatites, alkalic rocks and carbonatites, and in placers derived from these rocks. Known occurrences in New Mexico are restricted to pegmatites and associated placers and to alkalic rocks and carbonatite.

In New Mexico to the present time, limited production has come principally from pegmatites of the Petaca district, Rio Arriba County (about 12,000 pounds columbite-tantalite), the Harding pegmatite, Taos County (about 12,000 pounds microlite), and the Pidlite pegmatite, Mora County (production figures unknown). Niobium-tantalum minerals are reported as minor accessory minerals in pegmatites of the following districts : Ojo Caliente, Rio Arriba County ; Elk Mountain, San Miguel County ; White Signal, Grant County; and Gold Hill, Grant and Hidalgo Counties (fig. 57). Niobium-tantalum minerals probably are present also as minor constituents in other pegmatite districts of the State.

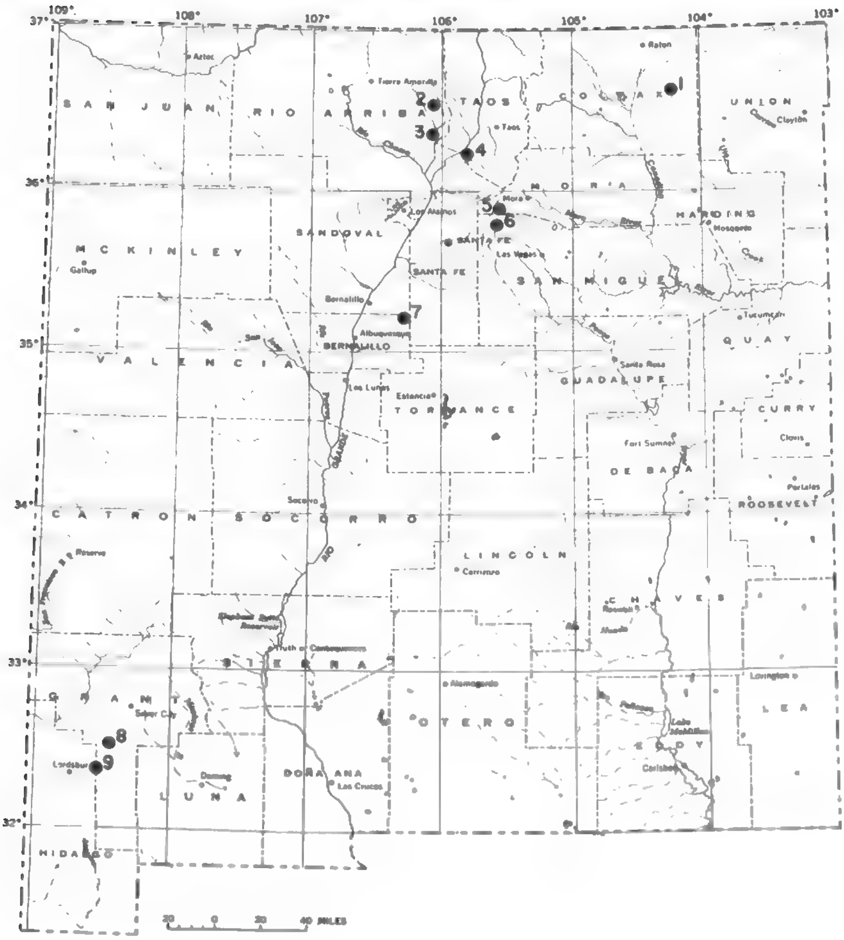
The Petaca district, long known for its mica production, contains at least 60 pegmatites with accessory columbite-tantalite and a lesser number with accessory samarskite. Although these minerals are two of the most common accessory minerals in the pegmatites, they are not abundant and for the most part are disseminated or are irregularly distributed. These minerals, however, commonly are closely associated with albite in the albitized parts of the pegmatites (Jahns, 1946).

The pegmatites of the Petaca district occur in Precambrian quartzite, schist, and granite, and are considered by Jahns to be genetically related to the granite.

The Harding and Pidlite pegmatites differ from those of the Petaca district in being lithium-rich and with tantalum dominant over niobium. The Harding pegmatite (Montgomery, 1950) contains microlite, hatchettolite (uranium microlite), and tantalite closely associated with smoky quartz, albite, lepidolite, and spodumene in certain zones in the pegmatite. The pegmatite body is gently dipping with average thickness of about 60 feet, a strike width of 500 to 600 feet, and an axial dip length of about 1,000 feet. It intrudes Precambrian amphibolite and quartz-mica schist and is believed to be related to the Precambrian granite that crops out half a mile to the south.

The Pidlite pegmatite (Jahns, 1953) is about 30 miles southeast of the Harding and is very similar both in its assemblage of minerals and in its geologic setting. The pegmatite is distinctly zoned and certain lepidolite-rich zones contain microlite hachettolite, and columbite-tantalite. Columbite-tantalite also is one of the accessory minerals in the massive quartz zone and in the wall zone along with betafite. This pegmatite occurs with others of similar composition in a north-trending zone at least 2 miles long in Precambrian gneiss, amphibolite, and schist.

Minor amounts of columbite-tantalite, samarskite, euxenite, hatchettolite, and fergusonite have been reported in the Ojo Caliente and Elk Mountain districts (Jahns, 1946) and euxenite and samarskite in the Gold Hill and White Signal districts (unpublished reports).



DEPOSITS

1. Laughlin Peak area
2. Petaca district
3. Ojo Caliente district
4. Harding pegmatite
5. Pidlite pegmatite
6. Elk Mountain district
7. Monte Largo area
8. White Signal district
9. Gold Hill district

FIGURE 57.—Niobium and tantalum in New Mexico.

Placer deposits of columbite-tantalite have been reported both in the Petaca district and at the Harding pegmatite. The Petaca placers are in alluvium and eluvium near some of the larger pegmatites and are neither extensive nor rich. Small areas in the drainage below the Harding pegmatite have produced only a few hundred pounds of tantalite.

Two occurrences of niobium in New Mexico that appear to be related to alkalic rocks are in the Laughlin Peak area, Colfax County, and in the Monte Largo area, near San Antonito in Bernalillo County. In the Laughlin Peak area (C. M. Tschanz, written communication, 1955) some veins which cut phonolite and the Dakota Sandstone are rich in thorium, niobium, and rare earths and contain also carbonate, phosphorus, barium, and strontium. The niobium content in some veins is as much as 0.37 percent, but the minerals containing the niobium have not yet been identified. The veins are thought to be related to the phonolite.

Alkalic rocks in the Monte Largo area (Lambert, 1961) consists of meteigite (nepheline-pyroxene rock) and carbonatite(?) each as a single narrow dike in Precambrian rocks. The carbonatite(?) lies within a body of breccia of possible explosive origin and contains apatite, mica, and magnetite in a matrix of dolomite. A sample of this rock is reported to contain 0.295 percent Nb_2O_5, but no niobium-bearing minerals have yet been identified. Carbonatites associated with alkalic rock complexes contain large, low-grade deposits of niobium (in pyrochlore) in many parts of the world.

New Mexico, though ranking third in the United States as a past-producer of niobium and tantalum, cannot be expected to supply large quantities of these elements in the future. Pegmatites of the State, the only known commercial source, contain niobium-tantalum mostly in accessory minerals; the niobium-tantalum content of the deposits is for the most part small and unpredictable in distribution. Nearly all niobium-tantalum production has come as a byproduct in conjunction with mica, lithium-mineral, or beryl mining. An exception to this is the Harding mine where microlite was mined as the primary constituent in the years 1943-47, and more than 12,000 pounds of tantalum concentrate was produced. Reserves at the Harding, determined by the U.S. Bureau of Mines (1945), are about 90,000 tons of ore containing 0.15 percent microlite. This is equivalent to about 155,000 pounds of tantalum, which is only about a quarter of the 1962 domestic consumption. The Harding deposit, however, remains one of the largest known deposits of tantalum in the United States.

The small, low-grade placers do not constitute significant resources of niobium or tantalum. Alkalic rocks and carbonatites are potential sources of niobium in nearby regions in Colorado, and the existence of similar rocks in New Mexico opens the possibility of undiscovered deposits of this type being found through future geologic study.

REFRACTORY MINERALS_MAGNESITE AND BRUCITE

(By F. E. Kottlowski, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Magnesite (magnesium carbonate, $MgCO3$) and brucite (magnesium hydroxide, $Mg(OH)_2$) are used as raw materials in the manufacture of magnesium refractories. Calcining magnesite at medium and high temperatures produces caustic-calcined magnesia and refractory magnesia respectively. The caustic-calcined magnesia is used to manufacture oxychloride cement for heavy-duty interior flooring, to produce refractories and insulation, and in the chemical and paper industries. More than 90 percent (Bates, 1960) of the magnesite mined is calcined to produce refractory magnesia, used mainly in the steel industry but also in copper smelters, cement kilns, and other high-temperature furnaces. During World War II, magnesium metal was produced from the Gabbs, Nev., magnesite deposit.

The only commercial deposit of brucite known in the United States is at Gabbs, Nev. (Callaghan, 1933) .

During 1962 (Comstock and Baker, 1963), 492,000 tons of crude magnesite were mined in the United States from which 135,000 tons of refractory magnesia and 21,000 tons of caustic-calcined magnesia were produced. The raw ore came from Nevada and Washington. The U.S.S.R. was the leading world producer of crude magnesite, with the United States in fifth place.

Magnesite commonly occurs as crystalline masses that look like "marble" or coarsely crystalline dolomite and as dense bodies with a porcelainlike texture. Magnesite and dolomite resemble one another closely. They may, however, be distinguished by chemical analysis or by examination in index liquids under the microscope. The three types of commercial magnesite occurrences are (Davis, 1957), in order of decreasing size of the deposits : (1) crystalline replacement bodies in limestone and dolomite, formed by the action of magnesium-rich solutions on preexisting carbonate rocks; (2) dense replacement products of serpentinized rocks, deposited in veins, pockets, and shear zones by the action of carbonated waters of either magmatic or meteoric origin; and (3) in bedded playa-lake deposits as a chemical precipitate, in most places interbedded with limestone, dolomite, and clay. Clues to finding magnesite ores, therefore, would be (1) dolomite beds that have been intruded by igneous rocks of granitic to monzonitic composition, (2) deposits of serpentine, and (3) playa lake beds.

Brucite, a soft waxy mineral somewhat resembling talc, appears to have been a product of hydrothermal solutions in the Gabbs deposit. There it invades and replaces both magnesite and dolomite and lies close to the contact between these carbonate rocks and a large granodiorite mass.

Magnesite and brucite occur in New Mexico in possibly commercial deposits in the Organ and San Andres Mountains of east-central Dona Ana County and near Red Rock in southwestern Grant County. Scattered crystals of magnesite, small masses, and layers up to 1 inch thick occur amid the Permian potash-bearing beds of southeastern New Mexico in Eddy, Lea, and Chaves Counties. Some of the contact-metamorphosed deposits of the Fierro-Hanover mining district in east-central Grant County contain dense magnesite associated with magnetite and serpentine.

The magnesite near Red Rock is in small scattered deposits along the west side of Ash Creek in N1/2 sec. 17, T. 18 S., R. 18 W. (Hewitt, 1959, p. 126-127). The largest exposure is about 60 feet wide by 75 feet long and contains horizontally bedded magnesite, fine-grained quartz, and lenses of finely crystalline dolomite. The dolomite and fine-grained quartz were originally bedded sedimentary rocks that first have been veined by quartz and then veined and replaced by magnesite. The magnesite deposit is small and impure. It is 5 miles by ranch road from Red Rock and relatively inaccessible.

In the Organ Mountains, on the southeast and south sides of the range, scattered xenoliths of brucite-serpentine marble and of magnesite occur (Dunham, 1935). The country rock is quartz monzonite. Some of the xenoliths are large, being more than 1,000 feet long and 500 feet wide, and the magnesite and brucite have selectively replaced beds in the lower Paleozoic sequence including parts of the El Paso Limestone, Montoya Dolomite, and Fusselman Dolomite.

Prospect pits are in lenses of magnesite that range from 1 to 5 feet thick. The larger deposits occur on the south side of South Canyon in sec. 35, T. 23 S., R. 4 E.; somewhat smaller bodies of metamorphosed Paleozoic carbonate rocks crop out along the east side of Target Range Canyon in N1/2 sec. 4, T. 24 S., R. 4 E. near the contact of the Paleozoic rocks and the quartz monzonite batholith of the Organ Mountains.

North of the village of Organ in the southwestern San Andres Mountains, a few impure beds of magnesite occur within contact-metamorphosed parts of the Montoya and Fusselman Dolomites near the contact with the quartz monzonite. These lenses of dolomite and magnesite are poorly exposed in a few prospect pits in NE1/4 sec. 31, T. 21 S., R. 4 E. The deposits along with the magnesite of the southern Organ Mountains are within White Sands Missile Range and are not open to commercial exploitation.

Thick dolomites are intruded by many large bodies of igneous rocks in southwestern New Mexico (Kottlowski, 1957) . The difficulty of distinguishing valuable deposits of magnesite from common dolomite or limestone "marble" allows the possibility that large magnesite-brucite bodies are present in New Mexico and still await discovery despite widespread prospecting for metallic deposits.

TALC, PYROPHYLLITE, AND RICOLITE

(By F. E. Kottlowski, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Talc is a soft, whitish to greenish-gray mineral with pearly luster and greasy feel. It has a perfect basal cleavage, occurs in massive or foliated aggregates, and is a hydrous magnesium silicate. Large bodies of the pure mineral are rare, and in commercial usage the term "talc" refers to rocks composed of magnesium silicates, in which the mineral talc is dominant or abundant. Tremolite, anthophyllite, and serpentine are the other normal constituents, along with carbonate minerals and silica.

The term "steatite" is at times applied to any massive talcose rock but is usually restricted to high-purity mineral talc that is used as an

ingredient of electronic insulators. Commercial steatite must not contain more than 1.5 percent each of CaO and Fe_2O_3, nor more than 4 percent of Al_2O_3 according to Bates (1960, p. 329). The massive soft talcose rock sawed into special purpose dimension stone such as electrical panels and chemical-laboratory sinks is called soapstone, block talc, or lava.

Pyrophyllite is similar to talc in its uses and its properties, being a soft, light-colored mineral occurring as compact, foliated, and acicular masses. It differs in being a hydrous aluminum silicate, and in its occurrence in metamorphosed acidic volcanic rocks.

The principal uses of ground talc are (Chidester, Engel, and Wright, 1964, p. 10-13) in ceramics, paint, insecticides, roofing, rubber, paper, asphalt filler, textiles, cosmetics, foundry facings, and food processing. Sawed and shaped slabs of soapstone are used for sinks, electrical base plates, and bench tops. Crayons and carvings are made from lump talc. Block steatite, designated a strategic mineral, is used for electronic insulators.

Talc may be ground to a brilliant white powder that is soft, smooth, and has great covering or hiding power and high lubricating ability. It has a high fusion point, high dielectric strength, low electrical conductivity, and is chemically relatively inert and therefore resistant to acids. When used in ceramics (as was about 35 percent of U.S. production during 1962), talc has a low firing shrinkage and the magnesia content acts as a flux.

Talc occurs in metamorphosed sedimentary rocks, chiefly dolomite, in metamorphosed volcanic rocks, and with the ultramafic and mafic rocks (rocks rich in ferromagnesium minerals and low in silica), serpentinite, dunite, gabbro, and peridotite. The deposits, restricted to areas of folding, faulting, and metamorphism, may be surrounded by country rocks of other types that are altered to talcose rock. Most of the deposits of talc appear to have been formed by selective replacement owing to the action of dilute hot solutions from diabasic or granitic intrusive masses (Bates, 1960, p. 338; Hess, 1933; Chidester and others, 1964, p. 13-21).

Small amounts of pyrophyllite, mostly paper-thin layers, occur in the Harding Mine and the Hondo Canyon area of Taos County. Sparse, thin micaceous flakes of talc have been found with sylvite and halite in the potash-bearing beds of Eddy and Lea Counties. Talc and talcose rock occurs in small quantities in many of the State's mining districts such as the Hermosa and Kingston districts in Sierra County, Council Rock and Jones districts in Socorro County, Cerrillos and Placers districts in Santa Fe County, Modoc district in Dona Ana County, and Chloride Flat and Fierro-Hanover districts in Grant County. Minor amounts of talc schist are reported from the Twining district in Taos County and the Petaca district in Rio Arriba County.

Ricolite, banded talc serpentinite, as well as some of the mottled and massive varieties of this talcose rock, has been quarried in small amounts from the Ash Creek area, 4 miles northeast of Red Rock in southwestern Grant County (NW$^1/_4$ sec. 16, T. 18 S., R. 18 W.) . The striking colors of ricolite vary from light yellow-green to dark green with shades of red, yellow, blue, brown, tan, and cream. It is easily worked and polished and has had limited use as interior wainscoting and for small carved decorative objects such as bookends and ashtrays.

The talc serpentinite occurs as tabular xenoliths enclosed in Precambrian granite and diabase (Hewitt, 1959, p. 44-53) associated with serpentine marble and massive serpentinite. The ricolite consists of alternating bands of talc and of serpentine with flakes of chlorite, fracture fillings of calcite and quartz, and cross-fiber veins of the asbestiform serpentine, chrysotile. Locally talc predominates over serpentine, the talc-rich variety being light cream and in bands up to several feet in thickness. The pods of relatively pure talc appear to be too small to be mined economically ; use of ricolite is limited because of its softness.

Talc has been mined in the Hembrillo Canyon area of the central San Andres Mountains in both Sierra and Dona Ana. Counties (Page, 1942; Kottlowski and others, 1956; Chidester and others, 1964, p. 37—38) . The deposits are associated with Precambrian argillite, phyllite, diabase, calcite, dolomite, and silica-carbonate rock. These rocks are overlain unconformably by the Cambrian and Ordovician Bliss Sandstone. The talc is in steeply dipping, lenticular masses 200 to 300 feet long and as much as 20 feet wide. The ore varies widely from white pure talc to dark-gray and green talcose argillite.

The Hembrillo mine on the south wall of the canyon (NE1/4 sec. 12, T. 16 S., R. 4 E.) was opened in two lenses of talc about 25 feet wide and 300 feet long to a depth of 40 to 60 feet during two periods, approximately 1917-23 and 1942 15, and may have yielded 10,000 tons of ore. The Red Rock mine on the north side of Hembrillo Canyon (SE1/4NW1/4 and W1/2NW1/4 sec. 1, T. 16 S., R. 4 E.) also explored two lenses of talc but only the lower ore body, 140 feet long by 20 feet wide, was mined by the Sierra Talc Co. About 2,000 tons were produced. Both mines closed in 1945 when the land was purchased for White Sands Proving Ground (now White Sands Missile Range). Early use was for cosmetics, whereas during World War II the talc was used for paint filler and as steatite.

Wright *(in* Chidester and others, 1964, p. 38) comments that some steatite-grade talc probably still is present at the Red Rock mine; ore reserves calculated by Page (1942, p. 12, 17) suggest that the ore exposed in 1942 was mostly mined out by 1945.

Similar metamorphic rocks (argillite and diabase) make up part of the Precambrian units along the east edge of the San Andres Mountains for a distance of 15 miles from Sulphur Canyon on the north to Mayberry Canyon on the south ; this is a rugged area not now accessible owing to its location in White Sands Missile Range. Future detailed geologic mapping of this area of Precambrian metamorphic rocks may uncover other talc deposits.

SILLIMANITE GROUP

(By E. C. Bingler, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Kyanite, sillimanite, andalusite, mullite, dumortierite, and topaz comprise the sillimanite group. The first three, polymorphs of Al_2SiO_5, are the most common, and of these, only kyanite is produced in large quantities in the United States. Heated in the presence of excess silica, kyanite is converted to mullite, a highly refractory and

tough substance used in the manufacture of furnace linings, crucibles, mortars, and other ceramic products.

Kyanite, sillimanite, and andalusite are generally formed by metamorphic processes; the first two are associated with dynamothermal metamorphism and the latter is usually confined to contact metamorphic aureoles in aluminous rocks. However, some kyanite has been found in veins and is presumed to be of pneumatolytic origin. Also, sillimanite and topaz have been reported as accessory minerals in potassium and silica-deficient igneous rocks. Because of their high specific gravity, minerals of the sillimanite group are frequently concentrated in secondary residual deposits, although none of these has proved to be economic.

Domestic production of kyanite is obtained from deposits in the southeastern piedmont states and California. The only reported production from New Mexico is a shipment in 1928 of 1,500 tons of kyanite ore from the Big Rock deposit, Petaca district, Rio Arriba County (Corey, 1960, p. 58) .

New Mexico occurrences of sillimanite-group minerals of possible economic interest are restricted to metamorphic complexes of Precambrian age. In the Precambrian sequence, kyanite and sillimanite are restricted to metaquartzite. These minerals are generally disseminated but in some areas, notably the Picuris Range and the Petaca district (fig. 55) , they form veins, pods, and lenses several feet thick (Miller, Montgomery, and Sutherland, 1963 ; Corey, 1960). Only the small deposits that underlie Mesa de la Jarita 55 miles north of Santa Fe have been mined, and in this area the amount of ore obtained has been disappointingly small. According to Corey (1960), these deposits formed in response to moderate metamorphism of pelitic silt, and he estimated that about 2 million tons of kyanite ore are present in the area.

Systematic exploration for sillimanite-group minerals is hampered by the meager knowledge available regarding the distribution and composition of rock units within the Precambrian. Where sillimanite and kyanite have been reported, they most often occur scattered sparsely throughout large masses of quartzite. The collection of basic data in areas of Precambrian exposures and research in the field of mineral recovery may eventually increase the economic potential of sillimanite-group minerals in New Mexico.

SALINES

(By B. R. Alto and R. S. Fulton, U.S. Geological Survey, Carlsbad, N. Mex., and L. B. Haigler, U.S. Geological Survey, Roswell, N. Mex.)

INTRODUCTION

For the purpose of this report the term "salines" includes potassium-,sodium-, and magnesium-bearing compounds that have been precipitated from concentrated solutions of natural or artificial brines. Other evaporites are described in accompanying chapters of this report.

The most important mineral commodities produced are the potassium compounds, most commonly refered to as potash. The term

,potash" has a number of definitions, several of which are contradictory. According to Ruhlman (1960, p. 652), the term has a dual meaning as follows: when used as a noun the word means the potassium oxide (K_2O) equivalent and, when used as an adjective, it means potassium compounds or potassium-bearing materials.

Salines of lesser economic importance in New Mexico are rock salt or halite (NaCl) and sodium sulfate (Na_2SO_4). Halite has been mined from playas and salt lakes in New Mexico. The principal halite production is now obtained from refinery waste of the potash industry. Sodium sulfate has been produced from shallow brine aquifers in southeast New Mexico.

GEOLOGIC OCCURRENCE

POTASSIUM MINERALS

Eastern New Mexico occupies part of the Permian basin ; the New Mexico part is divided into the Delaware basin and Northwestern shelf (fig. 24). The area is characterized by complex facies changes in rocks of Permian age. The Delaware basin, which extends southward into Texas, is the site of the thickest accumulation of Permian rocks in North America (Adams and others, 1939) .

Many rock units of Permian age in New Mexico contain saline evaporites. These units include the Yeso and San Andres Formations; the Artesia Group, which includes the Grayburg, Queen, Seven Rivers, Yates, and Tansill Formations in ascending order; and the Castile, Salado, and Rustler Formations. Salines are particularly abundant in the Castile and Salado Formations of Late Permian (Ochoa) age.

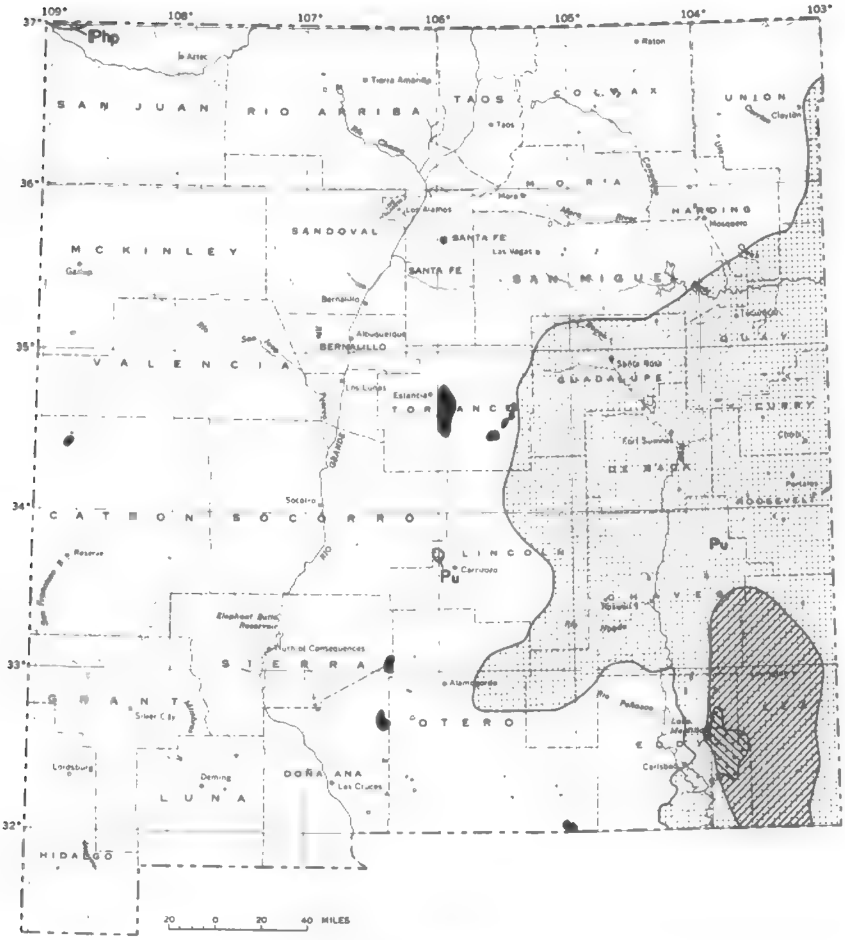
The most important occurrences are confined to the Salado Formation (fig. 58) . The following tabulation lists the principal potassium minerals and their composition, in decreasing order of abundance in southeastern New Mexico (Jones, 1954, p. 111). Also listed is the percentage K20 equivalent for each mineral.

Mineral	Chemical composition	K_2O equivalent
Polyhalite	$2CaSO_4 \cdot MgSO_4 \cdot K_2SO_4 \cdot 2H_2O$	15.6
Sylvite	KCl	63.1
Carnallite	$KCl \cdot MgCl_2 \cdot 6H_2O$	17.0
Langbeinite	$K_2SO_4 \cdot 2MgSO_4$	22.7
Kainite	$KCl \cdot MgSO_4 \cdot 3H_2O$	18.9
Leonite	$K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$	25.7

Polyhalite has the widest range, both vertically and laterally, of these minerals. Occurrences of the mineral have been reported through a stratigraphic range that includes, in ascending order, the Yates, Tansill, Salado, and Rustler Formations. Several evaporite minerals, other than those mentioned, are present in the Salado Formation but are not of economic importance (Schaller and Henderson, 1922).

Occurrences of potassium minerals in the Yates and Tansill Formations are sporadic and no deposits of economic size have been reported.

The Salado Formation contains the economic potash deposits of southeastern New Mexico. This formation has a broad lateral extent in eastern New Mexico, ranging from zero to about 2,450 feet in thick-



EXPLANATION

Sodium chloride, subsurface
Pu, Permian rocks, undivided
Php, Paradox Member of Hermosa Formation (Pennsylvanian age)

Potassium-bearing minerals reported in subsurface

Salt deposits, surface

Carlsbad mining district

Figure 58.—Salines in New Mexico.

ness, with the maximum thickness in the Delaware basin. Only a few outcrops of the formation are known and, at these localities, the formation appears only as a solution breccia. The upper surface of the formation, away from the outcrop, also shows the effect of solution by meteoric ground water, resulting in a solution breccia of varying thickness at the top of the unit. This breccia zone contains a highly mineralized aquifer as a result of the leaching of the soluble rocks. Jones (1959) described the Salado Formation as follows:

Below the top of the salt, the Salado is composed of thin-layered interstratified halite rock, argillaceous halite rock, sulfate rock (largely anhydrite and polyhalite rock with relative minor amounts of glauberite rock and magnesite rock), and fine-grained elastic rocks (sandstone, siltstone, and claystone), whose average proportions are as follows :

Rocky type	Percent
Halite rock	38.6
Argillaceous halite rock	45.0
Sulfate rock	12.5
Clastic rocks	3.9

The potassium mineral occurrences in the Salado Formation have been classified into four categories by Jones (1954), consisting of (1) accessory minerals; (2) stratified deposits in the sulfate strata ; (3) bedded deposits in the mixed halite-clastic strata ; and (4) vein or lens deposits that have replaced or displaced the strata. The bedded deposits display textural and structural evidence of secondary replacement and are economically the most important type of occurrence inasmuch as all of the potash production in New Mexico has come from deposits of this type.

In the potash-producing area of southeastern New Mexico, 12 such bedded deposits, or ore zones, have been recognized. The deposits have irregular form and are not all present through a given vertical section. With the exception of the uppermost ore zone, which occurs about 75 feet below the top of the Salado Formation, the remaining zones are confined to a stratigraphic interval of about 270 feet and occur in the middle part of the formation.

Of these ore zones, which are numbered in ascending order 1 through 12, 5 have been mined for potassium minerals. Only sylvite and langbeinite are exploited from the ore zones. These are the chief potash i minerals in the Carlsbad area because of their accumulation in economic quantity, their high K_2O percentage, their amenability to current refining practices, and the demand for the products that are produced.

The lowermost or first ore zone has yielded the greatest amount of potash. Mineralization in the zone consists principally of sylvite. This zone is mined by all of the active companies in the Carlsbad potash district. The fourth ore zone, consisting principally of langbeinite, which has a K_2O equivalent of 22.7 percent, is mined by International Minerals & Chemical Corp. and Duval Corp. In addition, the fifth ore zone, which contains mixed sylvite and langbeinite, is mined by International Minerals & Chemical Corp. United States Borax & Chemical Co. has done exploratory mining to a limited extent in the seventh ore zone, which contains sylvite. The 10th ore zone, consisting of sylvite, is mined by National Potash Co. and will be exploited by Kermac Potash Co. when mining is begun by this firm. The geologic structure in the Delaware basin and Northwest shelf area has an im-

portant bearing on the economics of potash exploration and mining. As a result of a low southeastward regional dip, the salt beds containing halite and potash minerals are found at greater depth to the east and south. On the west side of the Carlsbad potash area the first or lowermost ore zone is at depth of 700 to 1,000 feet while shafts farther to the east must be sunk to depths of about 1,700 feet to penetrate the 10th ore zone which is several hundred feet stratigraphically higher. In general, the attitude of the ore zones is nearly flat to gently rolling. However, at some localities, steep dips are present on the flanks of small anticlines.

HALITE

Castile Formation.—Halite is present in all of the units in which potassium minerals have been found, and the Castile Formation, which is confined areally to the Delaware basin and underlies the Salado Formation, contains several thick beds of halite. However, this formation, which consists entirely of evaporitic and saline rocks, is not known to contain potassium minerals. Away from the edge of the basin in the areas where the highly soluble halite beds have not undergone solution the Castile Formation ranges in thickness from 1,400 to more than 1,800 feet. Included in this thickness are two laterally persistent halite units. The lowermost rock salt bed has a thickness range of 250 to 325 feet and occurs from a few hundred feet to about 5,000 feet below the land surface. The medial halite unit occurs from a few hundred feet to about 4,000 feet below the surface and has a thickness range of about 150 to 250 feet. Locally, along the south boundary of New Mexico and near the axis of the Delaware basin, a third, upper halite unit is present. This unit is intercalated with anhydrite of the Castile Formation and passes entirely into anhydrite away from the central part of the basin. The uppermost halite unit has a maximum thickness of about 600 feet, with several anhydrite interbeds, and thins to zero thickness. The top of this unit varies in depth from about 2,900 to 3,700 feet from the land surface.

Salado Formation.—About 84 percent of the Salado Formation consists of halite or argillaceous halite. Jones (1954, p. 109) has described the halite in the Salado as occurring in two very distinct types of strata. One consists of a mixture of halite and elastic impurities of clay- and silt-sized quartz and silicate minerals. The other type does not contain elastics. Widespread lateral continuity is a characteristic of both types. Lang (1942, p. 63) made a detailed study of a part of the Salado Formation and discussed many of the sedimentary textures and structures. He reported that only locally are beds of clear halite present in the formation. Most of the halite in the formation is characteristically pale red to salmon pink. The color is frequently due to small amount of impurities such as hematite or silt and clay particles. Fournier (1961, p. 323) studied the clay content of the Salado Formation and determined that the predominant clay particles are alternating layers of chlorite and vermiculite.

Rustler Formation.—The Rustler Formation, which conformably overlies the Salado, contains beds of halite. Jones (1954) reported that four halite units are present within the Rustler Formation in the eastern part of the Delaware basin. To the west all of these salt units display the effects of solution and are represented by breccia, gypsum,

siltstone, and sandstone. The lowermost halite is about 15 feet above the base of the formation and ranges from 5 to 40 feet thick. The upper unit is about 30 feet below the top of the Rustler and has a thickness range of 10 to 30 feet. The other salt units occur in medial zone in the formation and range from 2 to 100 feet thick. North of the Delaware basin, halite beds in the Rustler thin and wedge out.

OTHER OCCURRENCES

Halite has also been reported in the Yeso, San Andres, Grayburg, Queen, Seven Rivers, Yates, and Tansill Formations. No estimates as to salt quality, bed thickness, or areal distribution have been made.

Halite was reported from the Standard Oil Co. of Texas Heard 1 well, SE1/4NW1/4 sec. 33, T. 6 S., R. 9 E., Lincoln County. This well was drilled for oil and gas and penetrated salt in an interval between 2,520 and 4,455 feet, in the Yeso Formation. The well to indicates that much of the interval is occupied by limestone, sandstone, shale, and anhydrite as well as salt.

In extreme northwestern New Mexico salt of the Paradox Member of the Hermosa Formation of Pennsylvanian age is known to be present in the subsurface (fig. 58). Hite and Gere (1958) show on a map of areal distribution of the salt that a small area of northwestern New Mexico is underlain by salt of this unit. The Texaco Inc. Navajo 1 well (sec. 17, T. 32 N., R. 18 W.) penetrated salt at a depth of 6,777 feet. No information is available regarding quality or thickness.

SURFACE OCCURRENCES

Catron County.—Zuni Salt Lake in Catron County (fig. 58) was reported by members of the Coronado Expedition in 1540 and it has been used as a source of salt by the Zuni Indians for several hundred years. Small amounts of salt are still harvested by the Zuni Indians here, but a greater amount is sold locally for the use of livestock. The lake is located in secs. 30, 31, T. 3 N., R. 18 W. and is about three-quarters of a mile across at its widest point. The lake is surrounded by basalt of Quaternary age and by the Mancos Shale of Cretaceous age, and is apparently a crater created by a volcanic explosion. The salt is marketed in its crude form, which is about 99 percent pure sodium chlorite. Traces of mirabilite (NA,S0, • $10H_20$) have been reported in this lake (Northrop, 1959, Talmage and Wootton, 1937).

Torrance County.—Numerous salt lakes cover a total of several thousand acres in Torrance County. Early Spanish explorers located these deposits, and later gathered the salt and transported it to silver mines in southern Chihuahua. Laguna del Perro, about 12 miles long, is the largest of the lakes. Salt deposits in Laguna Salina were gathered and sold commercially starting in 1915 and continuing into the 1930's. No attempts were made to refine the salt which was sold in its crude form. In addition to halite, sodium sulfate and magnesium sulfate have been reported in these lakes (Northrop, 1959 ; Talmage and Wootton, 1937).

Tularosa Basin.—Sodium sulfate minerals (mirabilite, Na_2SO_4; glauberite, Na_2Ca (SO4)2 and thenardite, Na_2SO_4) as well as halite and borax, $Na213,0_7$• $10H_20$, have been reported from Lake Lucero;

smaller lakes and alkali flats adjacent to Lake Lucero may be of the same composition. Deposits of sodium sulfate reportedly have been worked on an experimental basis in the Lake Lucero area with one shaft sunk to a depth of 90 feet, but no record of production is available. Lake Lucero is within White Sands National Monument and most of the other alkali flats and salt lakes are within White Sands Missile Range (Northrop, 1959; Talmage and Wootton, 1937).

Miscellaneous.—There are several other salt lakes located in New Mexico. Brine from Salt Lake southeast of Carlsbad has been used for oil-well-drilling fluids. Wells drilled for ground water in the Animas Valley have been reported by Reeder (1957, p. 28, table 1) to contain concentrations of fluoride of as much as 13 parts per million.

SALINE BRINES

Concentrated brine flowing on the top of the Salado Formation is expelled through seeps and springs into the Pecos River along the reach known as Malaga Bend in southern Eddy County (T. 24 S., R. 29 E.). A detailed geologic study of this area was made by Hale and others (1954) to determine if the brine inflow could be eliminated to improve the quality of the water in the Pecos River. Construction of the Malaga Bend Experimental Salinity Alleviation Project began in the fall of 1962 and was completed in July 1963.

Brine is diverted from entry into the river by pumping from the aquifer and transfer through a pipeline to a depression. Evaporation further concentrates the brine resulting in the deposition of salts. By the end of August 1964 it is estimated that 285,000 tons of solids had been precipitated in the depression (John S. Havens, personal communication). No analyses are available of the composition of the salt but the salines are thought to be a mixture of chlorides and sulfates, with sodium chloride the principal compound.

SALT CAVERNS

An important use for salt beds, the storage of liquid hydrocarbons in dissolved cavities, has been developed by the petroleum industry during recent years. By 1958 the total U.S. storage capacity in salt beds was reported as 36 million barrels (Pierce and Rich, 1962). Salt provides an excellent medium for underground storage. Costs for preparation of the cavities are relatively low as compared with conventionally mined cavities. Normally the salt is impervious to leakage, resulting in high recovery of the stored product. Studies have been made to determine the feasibility of using similar cavities for the storage of radioactive waste materials.

In southeastern New Mexico 19 salt caverns have been developed for liquefied petroleum gas storage. The total capacity of the underground storage is 660,395 barrels(New Mexico Oil Conservation Commission, written communication, September 1964).

SODIUM SULFATE

Sodium sulfate has been recovered from brines produced in southern Eddy County by Ozark-Mahoning Co. The brine occurs at shallow depth, 67 to 170 feet, in gypsum strata of the Castile Formation

(Lang, 1941; Hayes, 1964). Exploratory wells were drilled over an area in parts of T. 24 S. to T. 26 S., R. 25 E. to 27 E. Only a small number of the wells were capable of producing brine in economic quantities. The brine was gathered by tank truck and hauled to Monahans, Tex. for processing. This operation began in 1951 and ended in 1957.

THE POTASH INDUSTRY

(By B. R. Alto and R. S. Fulton, U.S. Geological Survey, Carlsbad, N. Mex., and L. B. Haigler, U.S. Geological Survey, Rosewell, N. Mex.)

HISTORY OF DISCOVERY AND DEVELOPMENT

A flourishing potash industry was developed in the American colonies during the 17th century by the early settlers, who manufactured crude potassium salts by leaching wood ash in iron pots. It is from this process that the name potash was derived. Later, following discovery of large natural potash reserves in Europe, the United States became dependent upon these sources. Total dependence upon foreign sources for this vital product spurred both Government and private industry to seek other sources.

Petroleum exploration in the Permian basin had revealed the widespread occurrence of saline rocks so that the area was of interest as a potential province for potassium mineralization. The first discovery of potassium salts from brine and cuttings, from the Spur well in Dickens County, Tex., was made in 1912 (Mansfield and Lang, 1934, p. 653). For several years exploration consisted of collection and examination of well cuttings from wildcat oil wells in the Permian basin by the Texas Bureau of Economic Geology and the U.S. Geological Survey.

The Shepard-Hudspeth bill, passed in 1926 by the U.S. Congress and modified in 1927, authorized the expenditure of $100,000 each year for a period of 5 years in the exploration for potash. The U.S. Bureau of Mines and the U.S. Geological Survey were in charge of the exploration program. The drilling program culminated in the completion of 23 core tests, of which 10 were drilled in New Mexico; 17 of the tests revealed the presence of potassium salts (Mansfield and Lang, 1934) .

The mineral sylvite was first discovered in New Mexico in 1925 in drill cuttings from the Snowden and McSweeney McNutt 1 well in section 4, T. 21 S., R. 30 E. in Eddy County. An offset core test was drilled adjacent to this well in 1926, which firmly established the presence of bedded sylvite beds. The McNutt well is recognized as the discovery well of the Carlsbad potash district.

After several years of exploratory drilling, the U.S. Potash Co. (now U.S. Borax & Chemical Co.) sank the first shaft in December 1929. The shaft was completed in January 1931 and the first production of potash was obtained in the same year. The Potash Co. of America began production of potash in 1934. Union Potash & Chemical Co., now International Minerals & Chemical Corp., began production of both sylvite and langbeinite in 1940. The two earlier companies were producing only sylvite ore. Duval Sulphur & Potash Co. began the production of potash from sylvite ore in 1951. In 1964, Duval Corp. also started producing langbeinite. The fifth producer of potash was Southwest Potash Co. whose production from sylvite deposits

began in 1952. National Potash Co. began production from sylvite deposits in 1957. A potential producer of potash is Kermac Potash Co., with production expected to begin late in 1965, also from sylvite-bearing ore.

MINING AND REFINING

Mining methods used by the industry in the Carlsbad district are principally of the room and pillar type. The relatively flat-lying potash beds are particularly suitable for this method. Recently, experimental long-wall mining has been tried with the use of continuous mining machines. Extraction rates in the conventional room and pillar method are in excess of 90 percent upon completion of the second mining or pillar removal phase. The mines are highly mechanized and use heavy duty equipment similar to that employed in underground coal mining. The U.S. Borax & Chemical Corp. employs the chemical refining process whereby crude ore is crushed and the sylvite dissolved in a potassium-deficient sodium chloride brine • from this solution the potassium chloride is reprecipitated by carefully controlling temperature and pressure. This company has also employed a gravity separation system, using tabling methods to upgrade the ore.

Methods of mechanical separation were studied by private firms and by the U.S. Bureau of Mines (Coghill and others, 1935). Research and study demonstrated that the methods of froth flotation could be applied to potash ores to separate sylvite from the gangue minerals, which consist principally of halite. As a result all companies except U.S. Borax & Chemical Corp. use the flotation method of refining sylvite ores. Crystallizing equipment is also used in conjunction with flotation to improve recovery of fine materials.

The refining of langbeinite ores is relatively simple. Fresh water is used to dissolve the gangue minerals, again principally halite, leaving the less soluble langbeinite product undissolved. In recent years selective flotation methods have been developed by International Minerals & Chemical Corp. which will allow it to recover both sylvite and langbeinite from mixed ores.

Much early work was done by the U.S. Bureau of Mines and others on methods of refining and treating the mineral polyhalite as a possible source of commercial potash. Laboratory research culminated in a number of reports on methods to treat and refine polyhalite (Wroth, 1930; Storch and Clarke, 1930; Storch, 1930; Storch and Fraas, 1931; Clarke and others, 1931; Storch and Fragen, 1931; Conley and others, 1932; Schoch, 1935 ; Conley and Partridge, 1944).

USES OF POTASSIUM PRODUCTS

The principal use (95 percent) for potassium products is as agricultural fertilizer. Potassium salts provided by the potash industry are used by chemical firms to manufacture other potassium salts which find a host of uses. These include detergents and soap, glass and ceramics, textiles and dyes, and chemicals and drugs. Other uses of potassium chemicals are : In the manufacture of gypsum board ; in the manufacture of titanium pigments ; as water purification chemicals ; for fur treatment and leather tanning; in pickle making, explosives, meat curing, and medicines. A great variety of other uses, too numerous to mention, are made of potassium chemicals (Ruhlman, 1960).

PRODUCTION

Potash.—In 1962 world production of marketable potassium salts totaled 10,700,000 tons K_2O equivalent. U.S. production totaled 2,-452,000 tons or 22.9 percent of world production. New Mexico production totaled 2,208,000 tons or 90 percent of U.S. production and 20.6 percent of world production (Lewis and Tucker, 1963, p. 999).

The entire New Mexico production of potash ore and refined potassium salts is obtained from 6 producing companies operating 10 mines in the vicinity of Carlsbad. A seventh company anticipates reaching production status by late 1965.

Mining operations are being conducted currently in 5 of the 12 principal mineralized zones recognized as being potentially commercial. All six producers are mining sylvite crude ore and two producers are mining langbeinite crude ore. Daily tonnages mined at the 10 producing mines vary from 2,500 to 15,000 tons. U.S. Geological Survey data indicate production of crude potash ores was 16.4 million tons in 1963, and total accumulated production of crude ores since 1931 was 202.6 million tons.

Ten grades of refined potassium salts are prepared for the consumer trade. Refilled potassium chloride salts consist of chemical grade, standard, coarse, and granular muriates; potassium sulfate salts consist of standard, coarse, and granular; potassium magnesium salts (langbeinite concentrates) consist of standard, coarse, and granular grades. In addition, all producers offer manure salts to the trade, these being ground potassium chloride crude ore with a minimum K_2O content of 20 percent. During 1963 Geological Survey data indicates New Mexico operators produced in excess of 4.5 million tons of refined salts with sales in excess of 4.2 million tons.

Halite.—The history of the development of the halite industry in the Carlsbad district parallels that of potash. Halite is the principal gangue mineral with the potash minerals and is disposed of as waste. A small, but growing, satellite industry which utilizes the waste salt produced by the potash firms has developed since the early days of potash production. Processing of the salt is relatively simple and consists essentially of drying, screening, sizing, and bagging. Some halite is also pressed into block salt for livestock.

Two companies in Carlsbad are actively engaged in the salt business. During 1963 these companies purchased 44,989 tons of crude salt, at a cost of $57,855, from potash mining companies for further processing and sale.

In 1963, 2,295 tons of salt valued at $10,213 were produced from Zuni Salt Lake in Catron County (Hays, 1963, p. 1). Figures for total past New Mexico halite production are not available; however, more than 500,000 tons have been produced.

Sodium sulfate brine.—During the 6-year period of operation, Ozark-Mahoning Co. produced 44,363 tons of brine containing sodium sulfate.

RESOURCE POTENTIAL

A recent canvass of southeastern New Mexico potash producers regarding presently minable reserves held under lease, together with data compiled by the Geological Survey regarding unleased reserves, indicates a crude sylvite ore tonnage reserve of approximately 1.3

billion tons with an average K_2O grade of approximately 17 percent. The crude langbeinite ore tonnage reserves are about 0.2 billion ton with an average K_2O grade of approximately 9 percent. The indicated reserves are present in beds containing not less than 14 percent K_2O sylvite, 8 percent K_2O as langbeinite, and in beds no less than 4 feet thick. Known deposits or concentrations of earnallite and polyhalite are not included in the above reserves.

With the successful extraction of mine pillars as demonstrated by New Mexico producers during the past 12 years, it is anticipated that mining extraction of 77 to 85 percent of the indicated reserves can be obtained and that refining efficiency will be about 85 to 90 percent.

Future growth and expansion of the New Mexico potash industry appears to hinge on the intensity of future development of high-grade deposits elsewhere as in Utah and Canada, the output from which will compete with New Mexico potash products in the major consuming areas of the United States.

SULFUR

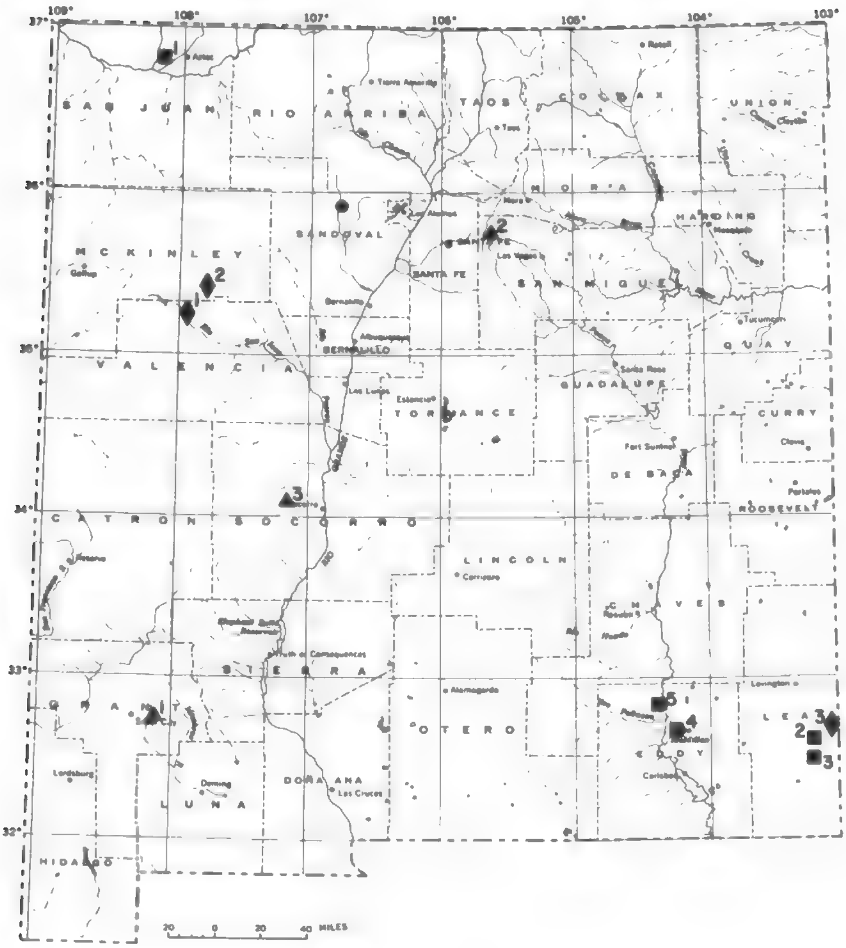
(By G. N. Broderick, U.S. Geological Survey, Washington, D.C.)

Sulfur, a nonmetallic element, is widespread in nature and occurs both in the free state and in combination with other elements. The largest domestic native sulfur deposits are associated with salt domes in Texas and Louisiana, where it is mined by the Frasch hot-water-melting process. Other sources include elemental sulfur in sedimentary and volcanic deposits, pyrite deposits, sulfide-ore concentration plants and smelters, hydrogen sulfide gas associated with natural gas and petroleum, coal-burning plants, and deposits of sulfate minerals (gypsum and anhydrite).

The principal demand for sulfur is in the manufacture of sulfuric acid which is used so extensively by modern industry that its consumption trend is considered an accurate indicator of the Nation's economic activity. The fertilizer industry is the largest sulfuric acid consumer; other large consumers are the chemical, paint and pigment, iron and steel, rayon, film, and petroleum industries. Sulfur is also used by the paper industry in the manufacture of sulfite pulp, and elemental sulfur is used by insecticide and rubber industries. Present use of sulfur in New Mexico is principally for uranium processing; a small amount of sulfur is used for producing insecticides and fungicides, refining petroleum, and in agriculture.

U.S. production of sulfur in all forms in 1963 amounted to 6.6 million long tons, of which 4.9 million long tons were from Frasch production. Free world production in 1963 totaled almost 20 million long tons.

New Mexico has produced little sulfur. Kelly (1962) states that from 1902 to 1904 a small quantity (reportedly 100 tons) was produced in Sandoval County from surficial deposits associated with hot springs. Since 1953, sulfur has been produced from natural gas. Locations of the native sulfur deposits in Sandoval County, sulfur-extraction plants, mining districts containing sulfide ores, and sulfuric acids plans are shown on figure 59.



EXPLANATION

Native sulfur deposit
Jemez sulfur district

Sulfur-extraction plants
1. Farmington
2. Monument
3. Eunice
4. Empire Abo
5. Artesia

Mining districts
1. Central district
2. Pecos mine
3. Magdalena district

Sulfuric acid plants
1. Bluewater
2. Ambrosia Lake
3. Hobbs

FIGURE 59.—Sulfur in New Mexico.

Sulfur occurs around some of the vents and fumaroles associated with hot springs in the Jemez Sulfur district in Sandoval County. One deposit, 4.5 miles north of Jemez Springs, extends about 400 feet along the west bank of the Jemez River and is 60 to 75 feet wide (Wideman, 1957). It consists of residual material derived from Carboniferous limestone leached by acidulated water and permeated by sulfurous vapors, which deposited sulfur irregularly in crevices and pores in the upper few feet of the rock. The deposit is a thin layer measuring only 2 to $3^1/_2$ feet thick. Samples of the material contained from 15 to 39 percent free sulfur and from 6 to 8.5 percent of sulfur combined as sulfate (Mansfield, 1921).

Another deposit, locally called Sulfur Springs, about 14 miles north of Jemez Springs, was reported to contain 60 percent sulfur. It was mined in 1902-04 from underground workings extending over a roughly circular area more than 600 feet in diameter. Vapors escaping from numerous vents in rhyolite deposited sulfur "on the walls of the vents, lining them with beautiful acicular or stout yellow crystals." (Mansfield, 1921, p. 368) .

Native sulfur is reported also to occur north of Lone Mountain or Red Peak near White Oaks in Lincoln County (Day, 1886), near Artesia in Eddy County, in Otero County near the Texas border, in an extinct volcanic cone north of Tres Piedras in Rio Arriba County, in La Bajada district in Santa Fe County, and southwest of Clines Corners in Torrance County (Northrop, 1959). These deposits are not significant potential sources of commercial sulfur.

The recovery of sulfur from natural gas in New Mexico was started in 1953 when two plants began producing : the Imperial Sulfur & Acid Co. plant near Farmington, San Juan County ; and the General Chemical Division, Allied Chemical Corp. plant at Monument, Lea. County, operated by the Warren Petroleum Co.

In 1954, El Paso Natural Gas Co. opened its Eunice plant near Oil Center, Lea County, and purchased the Farmington plant of Imperial Sulfur & Acid Co. The Farmington plant, rated at 1 ton of sulfur per hour, was later dismantled because of the low sulfur content of the gas produced from the Barker Dome field. Low sulfur content of the gas supplying the Eunice plant led to its closing in 1960.

Production of elemental sulfur at the plant at Monument was intermittent and in 1958 the plant was idle; plans called for its being dismantled owing to the low sulfur content of the gas supply.

Pan American Petroleum Corp., in 1960, placed a 12-ton-per-day sulfur recovery unit in operation at its Empire Abo gasoline plant 13 miles southeast of Artesia. This plant and the Artesia plant of Phillips Petroleum Co. were reported in production in 1963.

Sulfuric acid production in New Mexico started in 1955 when a 100-ton-per-day contact acid plant was completed by the Anaconda Co. at Bluewater. A second plant was completed in 1958 by Kermac Nuclear Fuels Corp. at Ambrosia Lake ; this unit was rated at 400 tons per day. Molten sulfur from Texas is used as a raw material. In 1962 Climax Chemical Co. completed an acid plant at Hobbs.

Gypsum and anhydrite are abundant in New Mexico, but sulfur has not been recovered from these deposits and it does not seem likely to be used as a source of sulfur in the near future.

Possible future production of sulfur from oil and gas fields in the San Juan basin of northwestern New Mexico and the Delaware basin of southeastern New Mexico constitutes a potentially large sulfur resource in the state.

The sulfide ores of various metalliferous deposits in New Mexico are also potential sources of sulfur. Most of the known reserve is in the Central district in Grant County, the Pecos mine in San Miguel County (Harley, 1940), and the Magdalena district in Socorro County (Loughlin and Koschmann, 1942). Sulfur has not been produced commercially from these deposits.

CLAYS

(By S. H. Patterson, U.S. Geological Survey, Beltsville, Md., and R. W. Holmes, U.S. Bureau of Mines, Denver, Colo.)

ADOBE, BENTONITE, CLAY, AND MEERSCHAUM

Clay materials have been used for building construction in New Mexico for many centuries, for Indians were making crudely shaped adobe blocks prior to the arrival of the first Spanish settlers (Whittemore and others, 1941, p. 2). Adobe was the most common building material for many years and is still used in new construction, particularly in rural areas. The extensive use of sun-dried adobe prevented the expansion of New Mexico's brick and tile industry at the same rate as in other States. Also, none of the very valuable clays that can be sold at distant markets have been mined on a large scale in the State. Therefore, the total clay produced in New Mexico through 1933, not including adobe and meerschaum, was 142,763 short tons valued at $305,540 (Talmage and Wootton, 1937, p. 71), and clay production in recent years, listed in the following table, has not been large. In 1961 New Mexico ranked as the 39th State in total tonnage and 35th in value of clay produced, and in 1962 it was 41st in tonnage and 35th in value, according to statistical data published in the U.S. Bureau of Mines Minerals Yearbooks (table 411.

TABLE 41.—*Clay production in New Mexico, 1950–62* [1]

Year	Quantity (thousands of short tons)	Value (thousands of dollars)	Year	Quantity (thousands of short tons)	Value (thousands of dollars)
1950	63	78	1957	33	83
1951	76	149	1958	40	73
1952	58	108	1959	45	77
1953	49	104	1960	56	132
1954	48	83	1961	67	165
1955	45	109	1962	52	156
1956	40	95			

[1] Figures for some years exclude tonnages and values, which cannot be disclosed, of certain clays.

Source: U.S. Bureau of Mines Minerals Yearbooks.

The clay materials now produced commercially or consumed locally are miscellaneous clays used in the manufacture of brick, tile, sewer pipe, and portland cement; loam and soil used for adobe; fire clay used in low- and moderate-heat-duty refractory products; and pottery

clay. Minor quantities of miscellaneous clays are occasionally produced for use in drilling mud. Bentonite has been produced in the State, but the only bentonite plant operating in 1964 is at Gallup and it processes bentonite mined in Arizona. Virtually all the meerschaum mined in the United States came from two districts in Grant County prior to World War I, and there has been no recent production.

The suitability of clays in New Mexico for various uses depends on physical properties that are controlled by the mineral and chemical composition of the clay. Clays are natural, earthy, generally plastic materials composed of very fine particles (clay minerals) which are principally hydrous aluminum silicates, but they may contain small quantities of iron, magnesium, potassium, sodium, calcium, and other ions. The common clay minerals in New Mexico include kaolinite, montmorillonite, illite, halloysite, sepiolite, chlorite, and mixed-layer clay minerals. All clays contain nonclay mineral impurities; quartz, cristobalite, feldspar, titanium minerals, carbonate minerals, and mica are common in many clays and gypsum and organic matter are abundant in others. The value of clays for most uses varies directly with the purity of the clay mineral present; however, for some products nonclay minerals or organic matter having certain properties are important. Physical properties of clays, one or more of which make them suitable for different uses, include plasticity, bonding strength, color, vitrification range, deformation with drying and firing, resistance to high temperatures, gelation, wall-building properties, viscosity of slurries, swelling capacity, ion-exchange capacity, and absorbent properties. The chemical composition, mineral structure, methods of identification, and testing of various clays for different uses are summarized by Murray (1960) and described in detail by Grim (1953, 1962) ; a report by Klinefelter and Hamlin (1957) outlines many of the laboratory procedures used in evaluating clays.

Adobe.—Adobe has been used extensively as a building material in New Mexico since the time of the early Spanish settlers. Though no records on the amount of adobe used have been kept, it was estimated in 1937 (Talmage and Wootton, 1937, p. 43) that the value of adobe exceeds the combined value of all other building materials consumed in the State. Adobe consists of a mixture of clayey loam, straw, and water, which when sun dried becomes hard and durable. The material used for adobe is of variable composition, and much of it is calcareous. The chief requirements are that sufficient clay-size particles are present to form a workable material when wet and a cohesive block when dry, but too much clay of certain types may cause undesirable warping and cracking. Adobe dwellings have the reputation of being cool in summer and warm in winter, because they have walls of exceptional thickness; also, adobe has a low-heat transfer coefficient (Talmage and Wootton, 1937, p. 43). Methods of building construction using adobe have been described by Miller (1949) and Neubauer (1955).

Investigations have been made on the use of bitumens and Portland cement as bonding materials for adobe (Whittemore and others, 1941), both of which give much lower water absorption properties and greater durability than sun-dried adobe. Adobe bonded with emulsified asphalt was made near Albuquerque after World War II, but no pro-

duction has been reported in recent years. Little adobe bonded with portland cement has been made in the State.

Fired adobe is gaining in popularity as a building material in parts of California and Arizona, but only small quantities of fired adobe have been used in New_Mexico and none has been made locally.

Bentonite.—Bentonite is a clay that has altered from volcanic ash or tuff and it is ordinarily composed chiefly of montmorillonite. One kind of bentonite known as Wyoming type or sodium type has very high-swelling capacity, extremely fine particle size, and other properties that make it valuable for use in well-drilling mud, as a bonding material for foundry sands and in pelletizing fine-grained iron ores, where high dry strengths are required, and as a relatively impervious lining for reservoirs, irrigation ditches, and stock tanks. A second kind of bentonite called calcium bentonite, southern type, or nonswelling is mineralogically similar to the Wyoming type but has different physical properties. Nonswelling bentonites are ordinarily not as efficient in drilling muds as the Wyoming type but they are more suitable for bonding materials requiring high-green strength, for catalysts in refining petroleum, bleaching clays, and other purposes.

Bentonite occurs in most counties in New Mexico (Reynolds, 1952, p. 25) , but has been mined only on a small scale at a few localities. A plant built at Hatch in the 1930's processed bentonite for drilling mud until the early part of World War II. The bentonite was mined near the western boundary of Dona Ana County (fig. 60) at a point 3 miles north of the highway to Deming. These deposits are in the Santa Fe Group of Tertiary to Quaternary (?) age (F. E. Kottlowski, oral communication, Sept. 11, 1964). According to Reynolds (1952, p. 25), 1 ton of this bentonite would make 60 barrels of 15 centipoise viscosity drilling mud, a yield appreciably lower than high-quality Wyoming-type bentonite widely used for this purpose. One sample of bentonite from the vicinity of Hatch had excellent oil-bleaching properties after acid treatment (Nutting, 1943, p. 151) . Presumably, this sample came from the deposits that were mined for drilling mud. A second bentonite deposit, also in the Santa Fe Group, has been worked in Rio Arriba County, approximately 35 miles north of Santa Fe. This clay was used in the manufacture of washing powder in Albuquerque (Talmage and Wootton, 1937, p. 54). Small tonnages of bentonite have been mined at several places for local use in lining irrigation ditches and stock tanks.

Bentonite occurs in sedimentary rocks ranging in age from Permian (Talmage and Wootton, 1954, p. 54) to Quaternary (?). Many occurrences are less than 6 inches thick, and others, such as the very thick beds of Triassic, Jurassic, and Cretaceous ages, are excessively contaminated with shale and have little value. The best quality bentonite now known in New Mexico is of Tertiary age and it occurs in beds that were deposited in lakes, most of which were probably saline.

Large undeveloped bentonite deposits occur approximately 25 miles north of Socorro. These deposits are in the Santa Fe Group. Parts of them are as much as 15 feet thick (Spiegel, 1955, p. 39) and, according to Reynolds (1952, p. 25), they are extensive. The bentonite in these deposits is of variable quality, as indicated by a few test results in the files of the New Mexico Bureau of Mines and Mineral Resources (R. H. Weber, oral communication, September 1964).

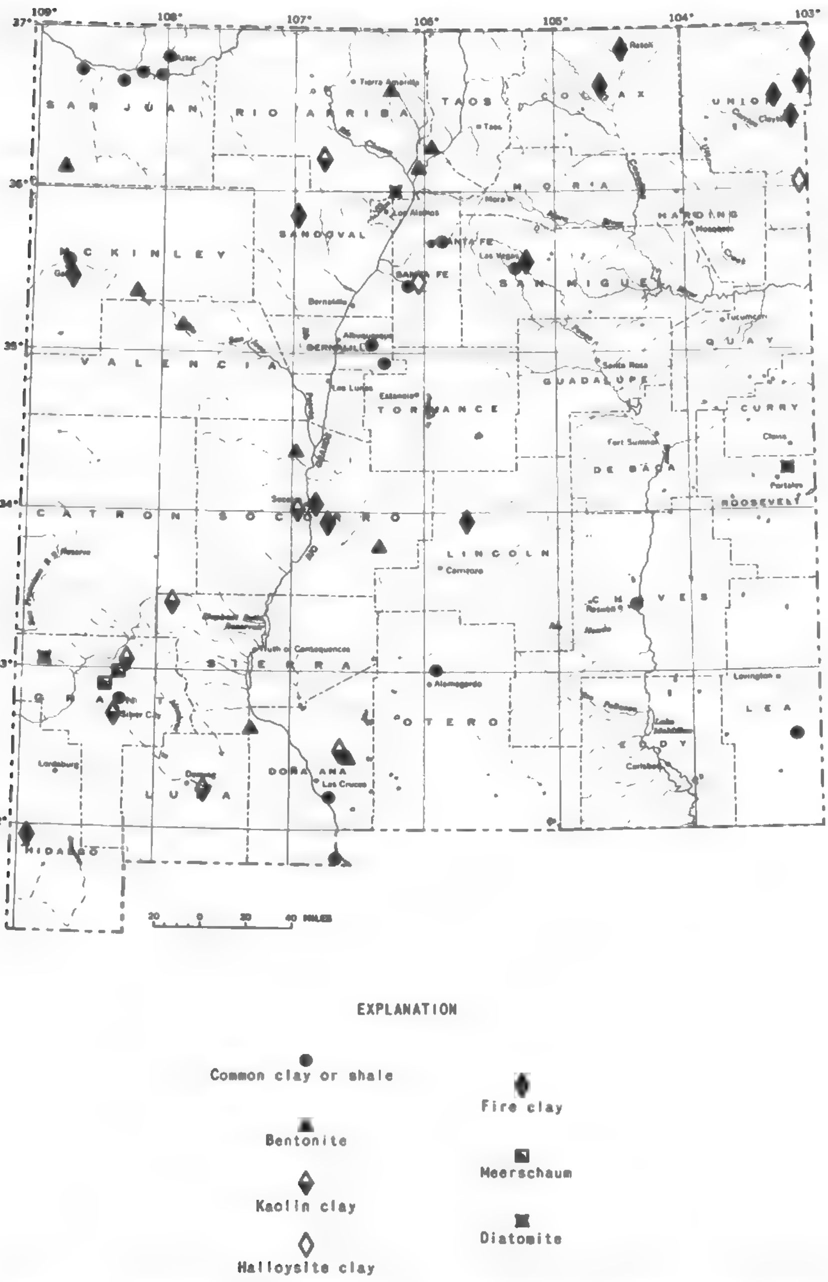


FIGURE 60.—Bentonite, clay, meerschaum, and diatomite deposits in New Mexico.

Some of it has properties that compare favorably with high-grade Wyoming type for use in drilling mud but much of these deposits may be valuable for other uses.

Scattered large deposits of bentonite and bentonitic shale of Cretaceous age occur in the southwestern part of San Juan and the northwestern part of McKinley Counties (Allen, 1955). According to the results of tests on four samples, both the drilling mud and bonding properties of this clay are too poor to compete with high-grade bentonite from other sources; however, an adequate appraisal of large deposits cannot be made from only four samples.

Kaolin and refractory clays.—Kaolin and refractory clays are a group of clays having related mineralogy and chemical composition. These clays have been classified by Klinefelter and Hamlin (1957, p. 6-8), according to uses, as : (1) kaolin or china clays, (2) ball clays, (3) halloysites, and (4) fire clays. Large quantities of fire clay and kaolin and smaller quantities of halloysite and ball clay are used in making refractory products. Both ball clay and kaolin are used in making tableware, whiteware, and other ceramic products. Well over a million tons of kaolin is used annually in coating and filling paper. Both halloysite and kaolin are used as catalysts in refining petroleum. Kaolins are used in adhesives, medicines, cosmetics, fillers, chemicals, and many other purposes (Murray, 1963, p. 17-19) ; and because of their content of $A1_20_3$, 39.50 percent in theoretically pure form, kaolins are commonly considered as a possible source of alumina. Clays that may be classified as kaolin, halloysite, and fire clay occur in New Mexico, but ball clay has not been discovered in the State.

The kaolin and refectory clays in New Mexico occur under various geologic conditions and have been used principally as fire clay and as mixtures with common clay and shale in making brick and tile. Kaolinitic clay at Socorro Mountain associated with altered rhyolite flows was once used for low-heat-duty firebrick at Socorro (Talmage and Wootton, 1937, p. 69). A light-colored clay material associated with igneous rocks in the Little Florida Mountains, Luna County, is presumably chiefly kaolinite. It has been used recently as a stabilizing admixture with other clays to obtain a uniformly colored heavy clay product (Hahn, 1963, p. 746). Deposits, part of which are chiefly kaolin and part montmorillonite and nonclay mineral impurities, have altered from volcanic rock along Copperas Creek in northern brant County. These deposits are now being mined to supply the Reese Mining & Manufacturing Co. plant at Silver City with a raw material for making light-colored face brick. Other deposits altered from igneous rock occur in the Little Burro Mountains, southwest of Silver City (Paige, 1916). Kaolin was discovered in a metal mine north of Organ, Dona Ana County (Richard, 1933), but this deposit was never mined on a large scale, suggesting that it is small or of low grade. Large deposits consisting of a mixture of highly crystalline kaolinite and cristobalite occur in hydrothermally altered tuffs and other volcanic rocks along the continental divide about 14 miles west of Winston, Sierra County. Parts of this deposit consist of rather uniform light-colored clay, but much of it contains appreciable vein quartz or other forms of silica and only partially altered volcanic rock. A few tons of clay from this deposit were used experimentally in making ceramic tile, and recently the deposits have been explored in some detail

and evaluations for use as paper coater are being made by private interests.

Kaolin clay occurs in sedimentary beds at the top of the Morrison Formation of Jurassic age and in the basal part of the overlying Dakota Sandstone of Cretaceous age at many places in northwestern New Mexico (Leopold, 1943). The best exposures of this clay are on Mesa Corral and Mesa del Camino, near the highest part of north-facing Mesa Alta, Rio Arriba County. At this locality bedded kaolin on an old erosion surface at the top of the Morrison Formation has been partly reworked and both kaolin clay chips and kaolin cement are present in the overlying Dakota Sandstone. These clay deposits have been prospected for about one-half mile along the northeastern face of Mesa Corral (Reeves, 1963) , and the kaolin was found to occur in lenticular bodies. In places the clay has been eroded completely, and in places it is as much as 6 feet thick. A sample of this clay tested in the U.S. Bureau of Mines laboratories (Holmes and Van Sant, in preparation) is superduty refractory clay, and a sample of the sandstone cemented with kaolin from the overlying Dakota Sandstone is a high-duty refractory material.

Halloysite occurs at several places in New Mexico, but mostly only as veins and small pockets in other rocks. The largest deposit yet discovered is northeast of Amistad, Union County. This deposit is a light-colored clay as much as 22 feet thick, occurring as a pocket or channel fill in the Dakota Sandstone of Cretaceous age. The clay is chiefly halloysite but may also contain gibbsite, as determined by differential thermal analyses conducted at the New Mexico Bureau of Mines and Mineral Resources. Drilling by the Filtrol Corp. disclosed only an estimated 5,000 tons of clay in the deposit (Baldwin and Muehlberger, 1959, p. 86). A second deposit of clay with the ceramic of halloysite, according to tests in the U.S. Bureau of Mines laboratories (Holmes and Van Sant, in preparation) , crops out in hydrothermally altered rocks near the old Cash Entry mine, Cerrillos mining district, Santa Fe County. The size and grace of this deposit have never been determined.

Clays and shales in sedimentary rocks of Pennsylvanian age have been used for refractory purposes at a few places. A shale south of Pratt, Hidalgo County, has been mined occasionally since about 1912 (Holmes and Van Sant, in preparation). This shale is used for refractory material in copper smelters. Clays in parts of the Sandia Formation, near outcrops of Precambrian granite east of Socorro, were formerly used for low-heat-duty products (Talmadge and Wootton, 1937, p. 69).

Fire clays, commonly associated with coal beds, occur in sedimentary formations of Cretaceous age in several counties. The largest production of these clays has been in the Gallup region, McKinley County, where thick beds of plastic, moderately thick beds of semiplastic, and thin seams of flint clay occur in the Mesaverde Group. These deposits were worked as early as 1898 (Shaler and Gardner, 1907, p. 299) , and small quantities of raw clay are still shipped occasionally for use as low- and moderate-heat-duty refractories. The highest production was in 1907 when 30,000 tons of fire-clay mortar, raw fire clay, and fire brick were shipped. Clay production in the Gallup coal field has been negligible in recent years, because the best grade clays are not thick

and are mined by underground methods. Strip-mining coal for the first time in the Gallup field began in 1962, and an inexpensive source of fire clay may become available.

Small-scale production of fire clay from strata of Cretaceous and Paleocene age has been reported at a number of localities, and a few undeveloped deposits occur at scattered localities. Clays and shales in the Dakota Sandstone have been used for refractories at Ancho, LM-coln County (Griswold, 1959, pp. 106-107; Holmes and Van Sant, in preparation), and at Las Vegas, San Miguel County (Holmes and Van Sant, in preparation), and undeveloped deposits occur at several places near Clayton, Union County (Baldwin and Muehlberger, 1959; Glass-mire, 1957). Shales and clays in the Vermejo and Raton Formations were used many years ago in making coke ovens at Dawson, Colfax County, and are, therefore, probably at least low-grade refractory clays. Some of the clay in the Mesaverde Group mined for brick in the Carthage coal field, Socorro County (Talmage and Wootton, 1937, p. 69), may have been suitable for low-heat-duty fire brick, and beds in the Mesaverde Group near La Ventana, Sandoval County, are now known to be suitable for low-grade fire clay (Holmes and Van Sant, in preparation).

Miscellaneous clays and shales.—Common clays and shales used in making brick and tile and for other purposes have been mined at a number of places in New Mexico. Plants using these materials have operated at various times since 1900 at most centers of population, including Albuquerque, Santa Fe, Gallup, Aztec, Farmington, Flora Vista, Fruitland, Ship Rock, La Luz, Las Vegas, Socorro, San Antonio, Silver City, and others (Talmage and Wootton, 1937). Most of the plants supplied local markets and closed after such demands were satisfied. The only brick plant in operation in the summer of 1964 was that of the Kinney Brick Co., south of Albuquerque. The State pentitentiary plant at Santa Fe and the brick and tile plant at Gallup have suspended operations in recent years. A modern brick plant is under construction at Silver City by the Reese Mining & Manufacturing Co. and is intended to be in operation in the fall of 1964. This plant may increase the future consumption of clays in the State significantly. Much of the miscellaneous clay used by brick and tile plants in El Paso, Tex., in recent years has been mined in New Mexico, and miscellaneous clays are used in making portland cement at Albuquerque and, locally, in drilling mud.

Clays and shales for miscellaneous uses have been mined from several types of rocks, including altered volcanic rock and sedimentary formations ranging from shale of Devonian age to flood-plain alluvium of Recent age. The Devonian Percha Shale west of Silver City is now being mined to mix with clays from Copperas Creek to obtain colored brick. Clays and shales of Pennsylvanian age are mined east of Albuquerque for use in making portland cement by the Ideal Cement Co. and for brick by the Kinney Brick Co., Inc. (F. E. Kottlowski, oral communications, Sept. 11, 1964) ; they have been mined recently east of Mesquite, Dona Ana County, to supply brick plants in El Paso, Tex.; and they were formerly mined northeast of Santa Fe to supply the State penitentiary plant (Spiegel and Baldwin, 1963, p. 82). Clays and shales in the Mancos Shale and Mesaverde Group of Cretaceous age were mined for brick at a number of places in northwestern New Mexico (Shaler and Gardner,

1907), including the recently closed plant at Gallup; similar materials mined in the old Carthage coal field were used in the plant at Socorro; clay of Cretaceous age is mined at the Brickland pit in southern Dona Ana County and used in plants in El Paso, Tex.; the clay mined at the Cerrillos pit of the Kinney Brick Co., Inc., is presumably of Cretaceous age; and clays and shale of Cretaceous age have been used for brick on a small scale in northeastern New Mexico. Red gypsiferous highly plastic in clays of probable Tertiary age were dug near Monument, County, and used for drilling mud n the Hobbs oil field (Talmage and Wootton, 1937, p. 66), and small tonnages of organic shales in the Blanco pit, Chaves County, are also used in drilling mud (Kelly and others, 1961, pp. 696, 702; Kelly and others, 1957, p. 806) . Alluvial clays of Recent age were formerly used for low-quality brick at Albuquerque and Socorro (Talmage and Wootton, 1937, pp. 64, 69) .

Pottery clay.—Plastic clays have been used on a small scale in making pottery, chiefly Indian wares and art pottery objects. One material used was a dark shale interbedded with limestone of Pennsylvanian age (Talmage and Wootton, 1937, p. 67). This shale becomes plastic when ground and pugged, and fires nearly white. It was formerly used in making art pottery of Mexican design at the La Luz pottery works, Otero County. Plastic clays suitable for Indian wares are dug locally near Gamerco, McKinley County, and near Espanola, Rio Arriba County. A deposit of plastic pottery clay, which probably is kaolin altered from volcanic rock, in secs. 2 and 11, T. 23 N., R. 2 E., northwest of Santa Fe, has recently been opened to supply local ceramic needs. Other deposits that may be suitable for pottery and artistic ceramic products occur in the Clayton area, Union County (Glassmire, 1957, p. 6).

Meerschaum.—Meerschaum (sepiolite), 411₂02MgO3Si02, is a tough clay material so lightweight that dry meerschaum (German word for sea foam) will float on water. Meerschaum can be carved and shaped and has been used for nearly 200 years in making pipes and other articles for smokers, and small quantities have been used for a number of other purposes, including an absorbent for nitroglycerine. Most of the world's supplies of meerschaum have come from the Eskishehr district of Turkey, but it also occurs in Spain, Greece, Czechoslovakia, Morocco and elsewhere. Meerschaum was discovered along Sapillo Creek, Grant County, N. Mex., in 1875. An estimated 2 million pounds of meerschaum had been shipped before World War I (Bush, 1915, p. 943) from the meerschaum mining district, on Sapillo Creek approximately 24 miles north of Silver City, and from the Juniper district, along Bear Creek 12 miles northwest of Silver City. Production of meerschaum ceased shortly before World War I (Petar, 1934, p. 4-5), and the only recent meerschaum operation, other than by mineral collectors, was in 1943, when approximately 1,000 pounds was shipped for experimental purposes in an attempt to find improved materials for insulators in radios (Northrop, 1959, p. 455). In addition to the two districts in Grant County where meerschaum was mined, small pockets, veins, and lenses of this mineral have been identified northwest of Gallup (Balk and Sun, 1954, p. 110) and at several places in the vicinity of Socorro and elsewhere in the State (K H. Weber, oral commun., September 1964).

The meerschaum deposits in the Juniper mining district are described by Sterrett (1908) as occurring in nodules, veins, lenses, seams, and balls in limestone; and those in the meerschaum district by Talmage and Wootton (1937, p. 113) as in veins in igneous rock. In both districts, most of it occurs as fillings of fractures and joints and it is commonly associated with chert, quartz, calcite, and clay. Meerschaum nodules are irregular in shape and range in longest dimension from less than an inch to several inches. Some forms are massive and others are fibrous. One rare form occurring as thin coatings along joints and the walls of vugs has a leathery or felt-like appearance similar to "mountain leather." Most of the meerschaum is contaminated with quartz or calcite crystals and washing and drying is required before use (Talmage and Wootton, 1937, p. 113).

Because of its unpredictable occurrence in small masses, no attempts have been made to estimate the resources of meerschaum in New Mexico. Meerschaum can be used for many purposes and markets would develop if large, high-grade, cheaply mined deposits were available but, because of the occurrence of known deposits in small scattered commonly impure masses, the discovery of large pure deposits in New Mexico seems unlikely. Meerschaum in New Mexico will probably remain, as at present, of interest primarily to mineral collectors and to those who investigate it for scientific reasons.

RESOURCE POTENTIAL AND ECONOMIC CONSIDERATIONS

Resources of raw materials for making sun-dried adobe in New Mexico are inexhaustible, and probably very large quantities of material suitable for asphalt and cement-bonded adobe and fired adobe could be found. Almost any sandy soil or other fine-grained surficial materials, such as occur in cultivated clayey loams, slope wash accumulations in small valleys, and bolson deposits, is suitable for making sun-dried abode. Raw materials for asphalt and cement-bonded adobe are somewhat more restricted than for the sun-dried type. Fine-grained rock or soil, low in alkaline salts, is required for efficient bonding with bitumens (Whittemore and others, 1941), and very sandy material would be more efficient than clay-rich material in cement-bonded adobe. The restrictions on materials used in fired adobe are probably much less stringent than on clays and shales used in brick and tile. Suitable plastic clays and sandy materials that could be used in fired adobe occier at a number of places but none of them have been evaluated for this use.

The prospects for future bentonite production in New Mexico appear bright, although no significant quantities have been produced and adequate investigation of the known large deposits has not been undertaken. Some bentonite at scattered localities in the State, including deposits north of Socorro, is suitable for use in drilling mud, and possibly for other purposes, and probably deposits of sufficient size and grade for profitable mining can be found. Significant production of bentonite would add to the State's mineral economy, inasmuch as the value of high-grade Wyoming-type bentonite, used chiefly for drilling mud and bonding clays, was $14 a short ton (f.o.b. mines in 1962 (de Polo and Brett, 1963, p. 433)).

The prospects are also considered to be good for the discovery of bentonite of the high-grade "nonswelling" type now being mined

southeast of Sanders, Ariz., less than 10 miles from the New Mexico boundary. This bentonite is used for bleaching clay and catalysts and, after being activated and transferred to shipping points, has a value ranging from $45 to $165 per ton (Kiersch and Keller, 1955, p. 471). Bentonite mined from these deposits also supplies the bentonite plant at Gallup, the only one currently operating in New Mexico where a product used as a desiccant is processed. The lacustrine deposits near Sanders, Ariz., are assigned to the Bidahochi Formation of Pliocene age (Kiersch and Keller, 1955, fig. 1). Though the Sanders bentonite deposits are not known to extend into New Mexico, numerous areas containing sedimentary rocks of similar age do occur in the State and many areas are favorable for prospecting for this type of bentonite.

Neither the resources nor the prospects for future use of kaolin in New Mexico can be evaluated from information now available. The deposits associated with the altered volcanic rock west of Winston, Sierra County, and along Copperas Creek, Grant County, contain some highly crystalline kaolinite; the sedimentary deposits along the Morrison-Dakota contact in northwestern parts of the State also contain some high-grade kaolin, and small kaolin deposits occur at other localities. The kaolin associated with volcanic rock contains fine-grained mineral impurities and the known deposits in sedimentary rocks are small and scattered. Probably large-scale mining of high-value kaolins in New Mexico (Georgia kaolins, after various types of processing, sold for $11 to $68 per ton f.o.b. plant in 1962) must await the development of a cheap beneficiation process for the removal of impurities from the deposits associated with the volcanic rock or else the discovery of new high-grade kaolins. Nevertheless, future production of kaolin in the State is a definite possibility.

The State's resources of low- and moderate-heat-duty fire clay appear ample to fulfill limited local demand. Probably the deposits near Pratt, Hildago County, will continue to satisfy the requirements of nearby copper smelters for refractory clay. Clay to supply markets for low-heat-duty firebrick, such as for fireplaces in home construction, may come from fire clays at several localities. Coal stripping in the Gallup field also may uncover fire clay suitable for several products. Fire clay of the quality required for super-heat-duty refractories occurs in New Mexico, but known deposits are small or otherwise unfavorable for profitable mining and little likelihood exists for the establishment of a large refractory industry in the State in the foreseeable future.

The halloysite deposits now known in New Mexico are small and have little value. Though the discovery of large high-grade halloysite deposits in several areas is possible, geologic information now available offers little encouragement to the prospector.

The possibility of extracting alumina from clays in New Mexico has been given some consideration by private interests; however, the prospects for using clay for this purpose are not good. Profitable use of clays as a source of alumina would require very large deposits of high-grade cheaply mined clay. Probably the most recent consideration of the use of clay as a source of alumina has been with the kaolins in Georgia (Georgia Geological Survey, Georgia Mineral Newsletter, 1963, v. 16, no. 1-2, p. 43), which are 35 to 40 percent Al_2O_3 (Kesler, 1963, p. 8). Though scattered deposits and pockets in large deposits in New Mexico probably contain kaolin that is as much

as 35 percent Al_2O_3, no deposits of sufficient size and grade to be attractive for alumina extraction are known in the State.

Several of the clays and shales that have been used for structural clay products occur in inexhaustible quantities; however, New Mexico's brick and tile industry has operated at a reduced level in recent years because of raw material problems and for a number of economic reasons. The State Penitentiary plant at Santa Fe was closed to avoid competition with private industry. A second plant in the State closed because of excessive mining, labor, and fuel costs. Much of the high-quality brick sold in Albuquerque and other cities in the last few years has been imported from other states, because the clay and shale mined locally contain excessive carbonate minerals and have a limited range of fired colors. Although a part of the industry's problem is related to raw materials, there seems little doubt that ample resources of suitable miscellaneous clays exist in New Mexico. Adequate exploration and resource appraisal of clays and shales have been done at only a very few places, and many localities in the State are favorable for the occurrence of raw materials suitable for brick and tile. The most favorable places for finding suitable clays are in altered volcanic rocks, noncalcareous shales in various formations of Devonian, Pennsylvanian, Permian, and Cretaceous ages, and clays occurring under or associated with coal beds of Cretaceous age.

DIATOMITE

(By S. H. Patterson, U.S. Geological Survey, Beltsville, Md.)

Diatomite is a siliceous rock of sedimentary origin, which consists of the skeletal remains of a varied group of microscopic plants called diatoms. Diatomite is also referred to as diatomaceous earth, kieselguhr, and infusorial earth, and incorrectly as tripolite. Diatoms occur widely in sedimentary rocks ranging in age from Late Cretaceous to Recent, but the term diatomite is restricted to rock that is of a quality and purity suitable for commercial uses. Pure diatomite consists of opaline or hydrous silica with small quantities of alumina, iron oxide, alkalies, alkaline earths, and other minor constituents. Virtually all diatomite contains sand, silt, clay, carbonate, or other impurities of the type making up or related to the associated rocks, and in general the value varies inversely with the quantities of such contaminants.

Diatomite is a lightweight, light-colored, chalklike rock, and because of its light porous characteristics and chemical composition, it is suitable for many uses. The lightweight results from the intricate porous structure and wide variety of shapes of the microscopic diatoms, which prevent dense packing even under the weight of overlying rocks. Diatomite on a dry basis commonly weighs from 20 to 40 pounds per cubic foot. The industrial uses of diatomite are classified by Cummins (1960, p. 313) as (1) filtration, (2) mineral filler or extender, (3) insulation, (4) absorbent, (5) mild abrasive, (6) process applications, (7) source of reactive silica, (8) structural materials, (9) possolan for cement mixtures, (10) conditioning agent, and (11) miscellaneous.

Large diatomite deposits occur in many places in the world, but pure deposits in favorable locations for markets are limited. The United

States is presently the world's leading producer of diatomite. Most of the foreign production is in Europe and Africa, and small tonnages are produced in Canada, Central America, South America, Australia, New Zealand, and Korea. The United States exports substantial tonnages and imports, if any, are probably extremely small. The total U.S. production for the 3-year period 1960-62 amounted to 1,446,625 tons (Hartwell and Schreck, 1963, p. 531) . In recent years approximately three-fourths of the production has been in California, with Nevada, Oregon, and Washington following in order of importance. The average annual value per ton of diatomite suitable for various uses (Hartwell and Schreck, 1963, p. 533) is listed in the following table :

Use	1961	1962
Filtration	$59.77	$61.30
Insulation	47.61	45.13
Abrasives	137.00	137.00
Fillers	50.53	51.69
Miscellaneous	31.71	26.45
Weighted average	50.65	50.06

Diatomite has been mined only on a small scale in New Mexico. The deposits that have been worked are in the Jemez Mountains, and the pit is in sec. 22, T. 21 N., R. 7 E., Rio Arriba County (fig. 60). This diatomite was trucked to the J. H. Rhodes Pumice Co., Inc., plant, south of Santa Fe, where it was calcined and ground for use as an oil absorbent and floor sweep. Unsuccessful attempts were also made to process a grade suitable for filtration. Figures on tonnage produced are unavailable, but the total was probably not more than a few thousand tons, inasmuch as diatomite was processed only for a few months in 1953 and 1954.

The diatomite occurs in the Tesuque Formation of the Santa Fe Group. The diatoms are of a type that occurs elsewhere in saline lake deposits of Late Miocene to Late Pliocene age (K. E. Lohman, written communication, Sept. 26, 1958) . The diatomite is calcareous and contains fine-grained mineral impurities. The bed mined is approximately 10 feet thick, but the total thickness of diatomaceous rock is appreciably greater. Diatomite deposits in the area occur under thin overburden over an area of approximately one-quarter square mile, and they pass laterally beneath a cap rock of basalt for what may be a considerable distance. Presumably the resources of diatomite in this vicinity are large.

Information on which to appraise the diatomite resource potential in New Mexico is scanty, because no geological investigations have been made and no information is available on the grade of deposits. In addition to the large deposits that were mined in Rio Arriba County, large diatomite deposits occur in Grant County (New Mexico Bureau of Mines and Mineral Resources, New Mexico nonmetal resource map, 1958), and diatom-bearing beds occur at two localities in Roosevelt County (Northrop, 1959, p. 385). Numerous other areas in the central and western parts of the State contain sedimentary rocks that accumulated in lakes and are favorable for the occurrence of diatomite. None of these areas has been adequately prospected. It

is probable that the diatomite resources of New Mexico are large, and the prospects for the discovery of deposits suitable for several uses are favorable. The prospects for mining diatomite on a large scale do not appear bright for the immediate future. Several large and vigorous companies are now satisfying demand for diatomite from mines in California Nevada, Oregon, and Washington. Reserves of high-grade diatomite in several areas in these states are large, and these sources will probably continue to be the major ones in the United States.

Construction Materials

GYPSUM AND ANHYDRITE

(By R. H. Weber, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Gypsum (hydrous calcium sulfate, $CaSO_4 2H_2O$) and anhydrite (anhydrous calcium sulfate, $CaSO_4$) are closely related industrial minerals of value in the manufacture of construction materials and other products, as soil additives in agriculture, and as potential sources of industrial chemicals. Consumption is tied largely to the level of building construction.

Gypsum is much more widely used than anhydrite. The bulk of it is calcined for the manufacture of prefabricated wallboard and lath, building plaster, and related products (Larson, 1960). Raw (imcalcined) gypsum is used principally as a set retarder in portland cement, for which about 10 pounds of gypsum are incorporated in each barrel of finished cement. Smaller amounts are used for agricultural purposes, where raw gypsum improves the tilth of heavy alkaline soils, promotes leaching of harmfully excessive alkalies from irrigated soils, and provides essential calcium and sulfur in soils deficient in these elements (McGeorge, 1945; Kelley, 1951; Dregne and Chang, 1952; Chang and Dregne, 1955) .

Anhydrite is used to a lesser extent than gypsum as a cement retarder and for agricultural purposes. It is preferred over gypsum for the manufacture of ammonium sulfate and sulfuric acid in Europe because of its higher sulfur content, but current processes are not competitive in the United States with readily available supplies of elemental sulfur.

Gypsum and anhydrite are widely distributed rock-forming minerals, and important commercial deposits consist largely of beds of relatively high purity which were deposited from solution during the evaporation of sea water. Similar deposits were formed through evaporation of highly saline inland lakes. Individual beds or series of beds range from a fraction of an inch to several hundred feet in thickness, and the lateral extent is commonly measurable in miles. Gypsum is far more abundant at and near the surface, because of the ease of transformation from anhydrite by combination with water. The presence of even small amounts of admixed anhydrite seriously impairs the usefulness of gypsum for calcined products such as those used in wallboard and plaster. Leaching of gypsiferous beds by surface and ground waters, followed by recrystallization of earthy or cellular aggregates of gypsum with admixed impurities, form local

surficial deposits of gypsite which have proved amenable to exploitation for agricultural purposes. Of much more limited occurrence are undeveloped resources in gypsum dune sands, such as those of the White Sands in New Mexico.

The low unit value of crude gypsum, averaging $3.65 per ton in 1962, coupled with the weight and bulk of finished products, usually necessitates the location of products plants near mines and market areas. These factors have limited the development of abundant resources in unfavorable locations. Production costs also favor mining by open-pit methods, although 16 domestic mines were underground operations in 1962 as a result of the high quality of the ore or the nearness to market (Larson, 1960; Kuster and Mallory, 1963).

The United States is both the largest producer and consumer of gypsum. Domestic production of crude gypsum in 1962, from 70 active mines in 21 states, totaled nearly 10 million short tons valued at over $36 million (Kuster and Mallory, 1963). The marked appreciation resulting from manufacturing processes is reflected in the value of gypsum products in the United States in 1962, which totaled more than $390 million. Imports of crude gypsum during the same period rose to 5.4 million short tons, most of which came from Canada, with smaller amounts from Mexico, the Dominican Republic, and Jamaica. Economic advantages of marine transport over land freight shipments make imported crude gypsum competitive with domestic supplies in coastal areas. Resources of gypsum in the United States are estimated to be sufficient for 2,000 years of production at current rates (Larson, 1960).

The use of gypsum in New Mexico has had a long history, but it was not until 1960 that a sizable modern industry based on the manufacture of gypsum products was established. Rock gypsum and selenite crystals were shaped into ornaments and ground for pigments by prehistoric Indians inhabiting the area more than 1,000 years ago. Specific uses are poorly documented for the Spanish Colonial period, but it may be assumed that some of the more conspicuous deposits were known and may have been exploited to some extent for plasters and coatings. The unavailability of glass window panes led to the substitution of sheets cleaved from large selenite crystals, a practice that persisted into the American Territorial period. Coursed walls of adobe and stone locally were laid with an effective mortar of raw calcareous gypsite. Roof decks at Fort Craig were protected by a 3-inch coating of gypsum plaster prior to 1868. During the early 1900's, plaster calcining plants of record were in operation at several places, including Ancho, Elida, Oriental, and Alamogordo (Herrick, 1904; Jones, 1904, 1915 ; Darton, 1920). Subsequent years witnessed a general deterioration of the State's small gypsum industry, although there was sporadic use of both gypsum and gypsite for agricultural purposes.

The Tijeras plant, of the Ideal Cement Co., located east of Albuquerque, was opened in 1959. Gypsum used as a retarder in portland cement produced by this company initially was quarried about 5 miles north of the plant by the Duke City Gravel Products Co., from the Todilto Formation of Jurassic age. Mining operations were later shifted to the Tongue deposit, about 21 miles north of the plant, from which crude gypsum from an open-pit mine in the Todilto Formation is currently shipped by truck to Tij eras. The first shipments of gypsum products from the newly completed Rosario wallboard plant of Kaiser

Gypsum Co., Inc., were made in May 1960. The plant, located about 21 miles southwest of Santa Fe, adjoins outcrops of the Todilto Formation from which gypsum is mined by open-pit methods. An initial production rate of 220 carloads per month of crude gypsum and 120 million square feet of gypsum board was anticipated. According to Elston (1961, p. 164), operations at plant capacity would require 100,000 tons of gypsum annually together with markets extending from Louisiana to Wyoming. The second wallboard plant, north of Albuquerque, was completed late in 1960 by the American Gypsum Co. Gypsum from the Todilto Formation in the open pit mine of the White Mesa Gypsum Co., southwest of San Ysidro, Sandoval County, is trucked to the plant. Plant capacity was increased in 1963 and doubled in 1964. Current consumption of raw gypsum is reported to be 350 to 400 tons per day, yielding a monthly ouput of about 40 million square feet of wallboard. Markets are reported to extend from St. Louis to San Francisco (press release Albuquerque Journal, Aug. 9, 1964).

The production of gypsum in New Mexico during the past four years is as follows (Minerals Yearbooks 1960-62, preprint for 1963) :

	Short tons	Value
1963	179,000	$656,000
1962	151,000	564,000
1961	105,000	386,000
1960	55,000	193,000

No production is reported for 1959, although a small amount must have been used as a retarder by the Ideal Cement Co.

Inasmuch as the gypsum resources of New Mexico have been described at greater length in an available report of recent date (Weber and Kottlowski, 1959), only a brief summary is given herein. Except where otherwise noted, the features discussed below are drawn largely from that source.

Deposits of rock gypsum, gypsite, and buried anhydrite are widely distributed throughout a large part of New Mexico in rocks ranging in age from Pennsylvanian to Pleistocene, with local gypsum dune sands of Recent age (fig. 61; table 42). Large areas in the North-

TABLE 42.—*Surface distribution of gypsum-bearing units in New Mexico*

Map symbol (fig. 61)	North-central	Northwest	Southwest	South-central	Central	Southeast
Quat. dune				X	X	
Tr				X		
Kr			X			
Jt	X					
Pa						X.
Psa					X	
Pe			X			
Py		X		X	X	
Pah				X		
Pr				X		

eastern, northwestern, west-central, southwestern, and extreme eastern border sections of the State are, however, lacking in significant outcrops of gypsum beds. Chemical analyses of 20 samples of gypsum and gypsite from New Mexico are listed in table 43.

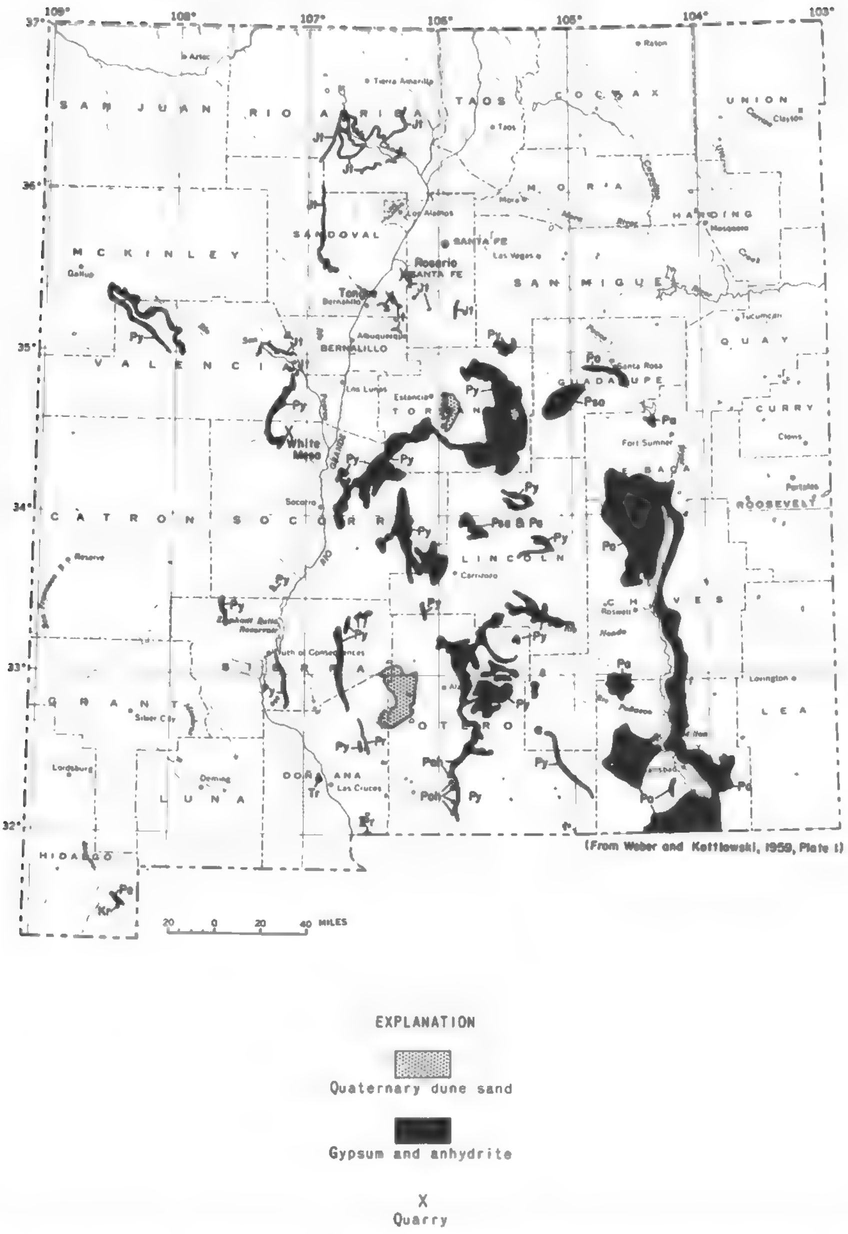


FIGURE 61.—Gypsum and anhydrite in New Mexico. Gypsum occurs in the following geologic units: Tr, Tertiary rocks; Kr, Lower Cretaceous rocks; Jt, Jurassic Todilto Formation; Pa, Permian Artesia Group (Rustler and Castile Formations shown with Artesia Group in Eddy County); Psa, Permian San Andres Formation; Pe, Permian Epitaph Dolomite; Py, Permian Yeso Formation; Pah, Permian Abo Formation and Hueco Limestone; Pr, Pennsylvanian rocks.

TABLE 43.—*Chemical analyses (in percent), of some gypsum samples from New Mexico*

(By Charles O. Parker & Co.)

Component	Sample numbers																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CaO	33.30	33.91	36.67	34.16	32.37	33.55	28.33	27.46	33.34	32.04	32.73	32.68	32.94	33.04	32.18	32.73	33.70	32.47	32.53	32.47
SO_3	46.03	44.95	47.81	45.16	43.64	45.16	38.42	37.74	46.05	46.10	46.40	46.98	45.65	47.36	46.76	46.62	42.93	44.69	43.64	45.80
H_2O (combined)	19.89	19.34	11.01	19.63	19.32	18.16	16.21	13.52	19.56	19.36	19.81	19.70	19.47	20.09	19.31	20.04	18.60	19.05	18.20	19.71
Fe_2O_3 and Al_2O_3	.10	.09	.15	.16	.43	.25	1.18	.70	.24	.42	.18	.30	.16	.23	.59	.23	1.56	1.10	.17	.16
SiO_2 (insoluble)	.21	.39	.60	.37	2.02	.57	13.98	19.48	.76	1.10	.40	.96	.16	.16	1.48	.37	2.53	2.81	.68	.29
MgO	.16	.11	.12	.27	.54	.36	.73	.23	.26	.20	.22	.14	.09	.00	.53	.09	.10	.09	.28	.46
CO_2	.59	1.97	3.66	1.17	2.24	2.16	1.87	1.25	1.17	.66	.37	.18	.55	.15	.77	.26	1.98	1.21	5.02	1.32
Total	100.28	100.76	100.02	100.92	100.56	100.21	100.72	100.38	101.38	100.88	100.11	100.94	99.02	101.12	101.62	100.34	101.40	101.42	100.47	100.21
$CaSO_4$ [1]	78.2	76.5	81.3	76.9	74.2	76.9	65.3	64.1	78.4	78.4	78.9	79.9	77.6	80.4	79.6	79.2	73.0	76.0	74.1	77.9
Gypsum [2]	97.8	95.0	92.3	95.6	93.0	94.8	80.9	77.4	96.5	96.9	98.6	98.4	98.1	99.4	97.4	99.0	90.4	93.8	92.0	97.4

[1] Calculated from amount of SO_3 available.
[2] Anhydrite from (1) plus combined water, adjusted to total 100 percent with impurities listed.

Note.—Identification and location of samples:

1. Sample 129–G1. Todilto gypsum near south boundary, Ojo del Espiritu Santo Grant. Grab sample from pipeline-trench excavation.
2. Sample 129–G2. Todilto gypsum, White Mesa deposit, NW¼ sec. 13, T. 15 N., R. 1 E. Drill-hole cuttings of upper 55 feet of gypsum.
3. Sample 129–G3. Todilto Formation, White Mesa deposit; location adjoins that of No. 2. Drill-hole cuttings of entire Todilto Formation, including basal limestone member.
4. Sample 174–G1. Todilto gypsum, Mesita deposit, NW¼ sec. 12, T. 9 N., R. 5 W. Random chip sample from old quarry face.
5. Sample 200–G1. Gypsite overlying Todilto gypsum, Suwanee deposit, NW¼ sec. 30, T. 8 N., R. 2 W. Grab sample.
6. Sample 232–G1. San Andres Formation gypsum, sec. 34, T. 5 N., R. 16 E., approximately ¾ mile northwest of Vaughn. 20-foot chip sample from old quarry face.
7. Sample 254–G1. Gypsum dune sand from stabilized longitudinal dune, eastern border of Salt Lakes, Pinos Wells Basin, SW¼ sec. 13, T. 3 N., R. 13 E. 7-foot channel sample from wall of blowout.
8. Sample 254–G2. Gypsum dune sand from active dune, ½ mile west of sample No. 7, SE¼ sec. 14, T. 3 N., R. 13 E. Grab sample.
9. Sample 273–G1. Gypsite from crystalline gypsite apron below main outcrop of Cañas gypsum member of Yeso Formation, north side of Mesa del Yeso, near south boundary Sevilleta Grant. Grab sample.
10. Sample 302–G1. San Andres Formation gypsum. Upper gypsum sequence in old plaster-mill quarry at Ancho, NE¼ sec. 25, T. 4 S., R. 11 E. Chip sample at 1-foot intervals.
11. Sample G300–58–1. Cañas gypsum member of Yeso Formation, south end of Chupadera Mesa, sec. 8, T. 6 S., R. 7 E. Chip-channel sample.
12. Sample G300–Pb. Gypsum from Torres member of Yeso Formation; same location as No. 11. Grab sample.
13. Sample G348–58–1. Gypsum in upper Yeso lower San Andres Formation, Phillips Hills, sec. 21, T. 10 S., R. 8 E. Chip-channel sample.
14. Sample G368–58–1. Yeso Formation gypsum, Associated Materials Co. mine, east-central Caballo Mountains, sec. 16, T. 15 S., R. 3 W. Chip-channel sample.
15. Sample G392–58–1. Yeso Formation gypsum, prospect cuts in southeastern Caballo Mountains, sec. 2, T. 17 S., R. 3 W. Chip-channel sample of gray and red porphyroblastic bed.
16. Sample G396–18732. Gypsum dune sand from White Sands National Monument, NE¼ sec. 32, T. 18 S., R. 7 E. Channel up steep face of 37-foot-high dune.
17. Sample G441–58–6. Gypsum from Tertiary lake beds, Apache Canyon, SW¼ sec. 31, T. 22 S., R. 1 E. Channel sample.
18. Sample G466–Pv. Gypsum (upper bed) in Panther Seep Formation, west foothills of northern Franklin Mountains. NW¼ sec. 33, T. 26 S., R. 4 E. Chip-channel sample.
19. Sample G475–58–2. Castile Formation banded gypsum, Yeso Hills, sec. 28, T. 26 S., R. 24 E. Grab sample.
20. Sample G475–58–3. Castile Formation nonbanded gypsum. Yeso Hills, sec. 28, T. 26 S., R. 24 E. Grab sample.

Source: From Weber and Kottlowski, 1959, table 1.

PENNSYLVANIAN GYPSUM

The Panther Seep Formation (Kottlowski and others, 1956, pp. 42—47) , of Pennsylvanian age, contains two zones of gypsum in the southern San Andres and northern Franklin Mountains, Dona Ana County. Outcrops extend from San Andres Canyon southward to Bear Creek in the Sari Andres Mountains and in the western foothills of the Franklin Mountains southwest of Anthony Gap. A similar gypsum unit in the northern Hueco Mountains was reported by Hardie (1958). The upper zone ranges in thickness from 65 to 100 feet in the San Andres Mountains and 10 to 35 feet in the Franklin Mountains. Gypsum from the Franklin Mountains locality has been utilized by the El Paso Cement Co.

PERMIAN GYPSUM AND ANHYDRITE

At the western edge of Otero (Horse) Mesa, south of New Mexico Highway 33, Otero County, a 25-foot bed of gypsum lies between redbeds typical of the Abo Formation and underlying limestones of the Hueco Limestone in a zone of intertonguing between these two Permian units. A laterally correlative gypsum bed was noted to the south (sec. 1, T. 25 S., R. 10 E. by Darton (1928, p. 220)). Kottlowski has assigned the gypsum to the Hueco (Weber and Kottlowski, 1959, p. 7-8).

Permian gypsum beds, that may be 200 to 300 feet thick, are exposed beneath thrust sheets in the Big Hatchet Mountains of southeastern Hidalgo County. A number of thin- to thick-anhydrite beds were cut by the Humble State BA 1 well southwest of the Hatchet Mountains. These beds were correlated by Robert A. Zeller, Jr., with the Epitaph Dolomite (Weber and Kottlowski, 1959, pp. 49-50; see Zeller, 1965).

The Yeso Formation of Permian age is highly gypsiferous in most areas, as indicated by the name (Yeso, Spanish word for gypsum). A major part of the State's total reserves of gypsum are within the Yeso Formation, whose wide distribution in central New Mexico (Valencia, Torrance, Socorro, Lincoln, Sierra, Dona Ana, and Otero Counties) makes it the most widely available source of gypsum (fig. 61). Gypsum makes up 12 percent of the 700-foot-thick type section of the Yeso northeast of Socorro (Needham and Bates, 1943, pp. 1658-1659) and 40 percent of the 1,580-foot-thick section in the San Andres Mountains. The Callas Gypsum Member ranges from 50 to 115 feet in thickness from Mesa del Yeso southeastward to the northern Sacramento Mountains, and from 50 to 170 feet on Chupadera Mesa. The Torres Member also contains numerous gypsum beds. Despite its wide distribution, however, gypsum in the Yeso Formation is in many places unfavorable for mining because of a thick capping of resistant beds that restrict the width of outcrop ; local interbeds of siltstone, sandstone, limestone, and dolomite ; and solution collapse, landslides, and tectonic deformation. Gypsite that is locally suitable for agricultural purposes is widespread on and adjacent to gypsiferous outcrops of the Yeso Formation. According to Kottlowski (Weber and Kottlowski, 1959, p. 41) , a 25-foot bed of gypsum in the Yeso Formation in the east-central Caballo Mountains has been mined for agricultural use in the Mesilla Valley.

Prominent beds of gypsum in the Permian San Andres Limestone are exposed at a number of places it central New Mexico. Significant localities of record include southeastern Valencia County east of Mesa del Oro, north-central Socorro County northeast of Socorro,

northeastern Socorro and southwestern Torrance Counties on Chupadera Mesa, southwestern Guadalupe County in the region around Vaughn, and western Lincoln County near Ancho and Carrizozo (Jicha, 1958, pp. 15-17; Wilpolt and Wanek, 1951; Smith, 1957, p. 55; Weber and Kottlowski, 1959, pp. 10-11, 30-33; Weber, 1964, p. 103). Gypsum beds 20 feet or more in thickness are fairly widespread, but exposures are poor in some of the more extensive tracts, such as those on Chupadera Mesa and near Vaughn. Solution collapse has seriously affected the distribution and continuity of the beds at a number of localities, as is particularly evident in the vicinity of Ancho and Carrizozo. Rock gypsum and associated gypsite in the San Andres were processed in a plaster mill at Ancho during the period from 1912 to 1922 (Budding, 1964, p. 86) .

Gypsum and anhydrite are prominent components of the Grayburg, Seven Rivers, and Tansill Formations of the Artesia Group of Permian age. Outcrops extend southward along the Pecos River Valley and its tributaries from the vicinity of Santa Rosa, Guadalupe County, to Carlsbad, Eddy County. Accessible outcrops of gypsum in the Seven Rivers and Tansill Formations are located west of Carlsbad, and along the east side of the Pecos Valley from Carlsbad northward to central DeBaca County. Economic possibilities of these beds are limited locally by their thinness, lateral gradation into dolomitic limestones and redbeds, and abrupt pinch outs.

The Upper Permian Castile and Rustler Formations in Eddy County contain large amounts of gypsum and anhydrite. In the Castile, laminated calcite-gypsum beds are characteristic in many outcrops, such as those in the Yeso Hills near the southern edge of Eddy County. As reported by Adams (1944, p. 1604), gypsum extends to depths of 500 feet, below which anhydrite appears. According to Hayes (1964, pp. 14-16, 56), massive, fine-grained white gypsum is the most abundantly exposed component of the Castile southeast of the Guadalupe Mountains. Beds as much as several hundred feet thick lie at or near the surface over an area of more than 100 square miles. Gypsum beds in the Rustler Formation are generally only poorly exposed in the Frontier Hills southwest of Carlsbad, and east of the Pecos River from near Carlsbad southward to the State line.

JURASSIC GYPSUM AND ANHYDRITE

The gypsum member of the Todilto Formation of Late Jurassic age contains some of the most important reserves of commercial-grade gypsum in the State. In contrast to the previously described marine deposits, the Todilto Formation is a product of deposition in an inland lake basin. Massive gypsum beds of the upper member are present only in the central part of the basin, whereas limestones and calcareous shales of the lower member predominate elsewhere. Outcrops are limited to northwestern and north-central New Mexico, extending southward along the eastern margin of the San Juan Basin, west of the Sierra Nacimiento, from near Abiquiu, Rio Arriba County, to San Ysidro, Sandoval County ; along the Rio San Jose near Mesita and Suwanee, Valencia County ; in the Tij eras Basin north of Tij eras, Bernalillo County; east and northeast of Placitas, Sandoval County; and in eastern Sandoval and western Santa Fe Counties from Rosario siding to west of Madrid and from Arroyo Tongue to southeast of

Hagan (Darton, 1920, pp. 177-144; Wood and Northrop, 1946; Rapaport and others, 1952; Stearns, 1953, p. 465; Kirkland, 1958; Weber and Kottlowski, 1959, pp. 12-29; Smith et al., 1961, pp. 11-13; Schlee and Moench, 1963; Moench and Puffett, 1963; Kelley, 1963). Thicknesses of the gypsum beds generally range between 50 and 100 feet. Well cuttings show that anhydrite prevails at depth, although hydration to gypsum appears to be complete in outcrops. The wide distribution of fairly broad outcrop benches of massive, high-grade gypsum with little or no overburden, in company with the favorable location and accessibility of the deposits, has led to rapid development and exploitation of the Todilto gypsum in recent years. Current mining operations are centered on White Mesa at San Ysidro (White Mesa Gypsum Co., for American Gypsum Co.), at Rosario (Kaiser Gypsum Co., Inc.), and at Tongue (Duke City Gravel Products Co., for Ideal Cement Co.). Minor past production has come from near Gallina for local use as plaster, from White Mesa for agricultural purposes, from Mesita for use as plaster and as a rock dust in coal mines, and from Suwanee for agricultural purposes. Undeveloped reserves are very large.

CRETACEOUS GYPSUM

Uppermost beds of the Lower Cretaceous rocks in southeastern Hidalgo County contain at least two beds of gypsum aggregating up to 60 feet in thickness, according to Robert A. Zeller, Jr. (Weber and Kottlowski, 1959, p. 49 ; see Zeller, 1965). Outcrops were noted in the foothills south of the Big Hatchet Mountains.

TERTIARY GYPSUM

Gypsum beds of Tertiary age are known to occur "* * * in the southern Robledo Mountains along Apache Canyon, 5 miles northwest of Las Cruces" (Weber and Kottlowski, 1959, pp. 46 47). Beds from 1 to 10 feet thick are within redbeds in the basal part of the Tertiary volcanic sequence. The nearness of these beds to the highly productive agricultural lands of the Mesilla Valley offers some advantages, which are partly diminished by seasonal difficulties of access.

QUATERNARY GYPSUM

Crystalline to massive gypsum beds of Quaternary and possibly late Tertiary age are exposed locally in the Tularosa Basin in Dona Ana and Otero Counties. Outcrops have been noted by Kottlowski around the edges of playa Lake Lucero and Alkali Flat, west of the White Sands, and eastward as far as Alamogordo (Weber and Kottlowski, 1959, pp. 40-41). These beds are, at least in part, products of deposition in saline lakes; locally, however, there are beds formed by consolidation and recrystallization of gypsum dune sands, and others that represent gypsiferous caliches. Although these indurated deposits contain large reserves of gyspum of potential commercial value, they are overshadowed in this area by extensive gypsum dune sands of higher purity (up to 99 percent gypsum). The best known of the dune tracts lies within White Sands National Monument where dune formation and migration are currently active. Large tracts of similar character also lie outside the monument boundaries to the

north. Kottlowski has tabulated the areas covered by relatively pure gypsum sands 10 to 50 feet thick (Weber and Kottlowski, 1959, pp. 38-39). Areas lying outside White Sands National Monument total 131 square miles containing nearly 4 billion tons of gypsum sand. Dunes of lower purity (about 75 percent gypsum) extend across an area of at least 190 square miles northward from the high-purity dune sands. Older, stabilized gypsum dunes south of the White Sands are more quartzose southeastward toward the Jarilla Mountains. Despite the vastness of the reserves of high-purity sands in this area, sufficient for several hundred years at the current rate of National consumption, their exploitation will be inhibited by their location within the "White Sands Missile Range.

Less extensive gypsum dune sands of lower purity border the eastern margins of three saline playa basins in Torrance County (Weber and Kottlowski 1959, pp. 35-38). The largest of these is in the southeastern part of the Estancia Valley where stabilized dunes, generally 50 feet or less in thickness, contain variable proportions of sand made up of selenite cleavage flakes with intermixed and included clay and silt. The western edge of the dune tract is about 31/2 miles east of Willard and is approximately coextensive with the clay hills area of Meinzer (1911, plate 1), which has a north-south length of 16 miles and a maximum width of a little more than 6 miles. Similar, though much less extensive, gypsum dune sands occur along the eastern border of the modern playa in the Encino Basin, about 3 miles south of Encino. An irregular tract of stabilized gypsum dunes several miles long and roughly half a, mile wide borders the eastern side of modern playas in the Pinos Wells Basin, about 5 miles east-northeast of the village of Pinos Wells. Wind scour in active blowouts has channeled the western face and crest of the main transverse dune ridge, exposing cross-bedded gypsum sands of greater purity (77 to 81 percent gypsum) than those in the Estancia and Encino Basins. Although apparently suitable for agricultural purposes, the gypsum sands of this region are at some distance from potential markets.

New Mexico is clearly endowed with vast resources of gypsum and anhydrite; reserves of gypsum at the surface could readily supply the total demands of the United States for hundreds of years. Existing gypsum products manufacturing facilities are sufficient to supply current requirements for construction materials within the State and the surrounding market areas served by these plants. Future growth will be closely related to the level of construction in the region, plus modest increases in local agricultural usage.

LIGHTWEIGHT AGGREGATES

(By R. H. Weber, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mex.)

Lightweight aggregates comprise a group of construction materials whose low density (low unit weight) results in a significant weight reduction in concrete and plaster when substituted for ordinary sand and gravel; additional benefits derive from increased thermal and accoustical insulative properties and from fire resistance. They owe their low density to a cellular structure, the density of the particles

decreasing with increasing porosity and thinness of the cell walls. Some, such as pumice, scoria, and diatomite, are natural lightweight aggregates whose porosity is a result of natural processes. Others, such as perlite, expanded shale, and vermiculite, owe their porosity to expansion or vesiculation during artificial heat treatment. Each of these, except for diatomite, which is largely used for other purposes (see clay minerals chapter), is discussed separately.

PERLITE

The term *perlite* was originally applied to natural siliceous *glasses* of volcanic origin characterized by abundant concentric fractures and commonly a pearly luster. The industrial term has been extended to include any volcanic glass that will expand appreciably by vesiculation under appropriate heat treatment, thus embracing also some obsidians, pitchstones, vitrophyres, and the resultant expanded products. True perlites, in the original sense, are sometimes distinguished from nonperlitic varieties in the trade by the term *onionskin perlite.*

Processing of crude perlite consists essentially of crushing and sizing to required particle sizes and gradation, followed by rapid heating in kilns or furnaces to temperatures of from 1,700° to 2,000° F. Rapid expansion of water vapor that is evolved while the particles are at temperatures in the softening range (viscously plastic) results in the formation of numerous bubble voids throughout each particle. When cooled, the particles are rigid and retain their cellular structure, which is similar to that of pumice. Volumetric expansion ratios of from less than 2 to more than 20 times are attainable, depending upon inherent properties of the crude perlite and controllable variations m heat treatment. Bulk densities of the expanded aggregate as low as 2 pounds per cubic foot have been obtained, ranging upward to that of the crude aggregate. Inasmuch as reductions in bulk density produced by increased ratios of expansion also result in progressive lowering in strength of the expanded aggregate, practical limits are set by the strength requirements of specific uses.

Current uses of expanded perlite, reported for 1962, are as follows (Hartwell and Schreck, 1963) : building plaster aggregates, 47 percent ; filter aids, 19 percent ; concrete aggregate, 16 percent; oil well cement, 6 percent; loose-fill insulation, 3 percent; other insulation and soil conditioners, 2 percent each; filler and wallboard, 1 percent each; and miscellaneous, 3 percent. Although lightweight plaster- and cement-aggregate uses are still the major ones, filter aids are now a significant factor among the minor products.

Perlite and related natural glasses are products of volcanic processes. Their distribution is accordingly limited to volcanic fields where they are associated with ordinary lava flows, volcanic breccias, and tuffs, particularly those of rhyolitic composition. Modes of occurrence of commercial perlites include lava flows and extrusive domes, plugs, pyroclastic breccias, welded tuffs, and shallow intrusive dikes and sills. Because the glassy state is relatively unstable, they tend to denitrify by crystallization with increasing age. They are also readily altered to clays, zeolites, and other minerals by solfataric, hot spring, and hydrothermal processes. As a consequence, commercial deposits are Tertiary or younger in age. The larger bodies attain thicknesses of several hundred feet and lateral extents of several miles. Minor

occurrences are widespread in which glassy phases form thin flow bands, lenses, narrow selvages of intrusive bodies and the bases of tuffs, scattered blocks in tuff breccias, and dispersed nodules. The water content, which is essential to the expansion process, commonly lies in the range of 3 to 5 percent but may be as low as 1.5 percent in expansible obsidians and as high as 10 percent in expansible pitchstones.

Deposits suitable for exploitation are limited to the larger bodies of uniform character that are free of excessive impurities, such as devitrified or altered zones, lithoidal flow bands, spherulites, and abundant phenocrysts. The low unit value of crude perlite usually precludes mining by other than open pit methods. Transportation costs tend to exclude deposits in remote locations. Carefully controlled laboratory and pilot mill testing are prerequisites to a determination of the suitability of a particular perlite for the manufacture of specification products. Such tests should include response to crushing and sizing as well as expansion characteristics (Stein and Murdock, 1955 ; Weber, 1955).

Although the expansibility of some volcanic glasses when heated to softening temperatures has been known for a number of years, an active industry based on the manufacture and use of expanded perlite aggregate dates only from 1946. Production increased steadily until the peak was reached in 1959, when 443,000 short tons of crude perlite was mined and 325,000 short tons was sold and used by producers in the United States (Hartwell and Schreck, 1963). Domestic production since 1959 has been slightly lower. Mine production in 1962 was 408,000 short tons of crude perlite, of which 320,000 short tons was sold and used; 238,000 tons of expanded perlite was produced during the same period. Average value of crushed, cleaned, and sized crude perlite sold to expanders in 1962 was $8.14 per ton, f.o.b. producers' plants. Average price of all, expanded perlite sold in 1962 was $52.80 per ton. Known deposits are limited to the Western States. Expansion plants were located in 29 States reaching from California to New Jersey (Hartwell and Schreck, 1963). The United States continues to be both the leading producer and consumer of crude perlite, only minor production having been reported from other countries. Canada has been the principal importer of perlite produced in the United States.

New Mexico is currently the leading producer of crude perlite in the United States. Output from the State in 1963 was 295,000 short tons sold or used, valued at $2.2 million. This constituted about 80 percent of the domestic production. Commercial production of perlite in New Mexico reportedly began about 1947, but it was not until early in 1949 that significant production commenced with operation of the open-pit mine of the Great Lakes Carbon Corp. near Socorro. During 1951, following activation of the F. E. Schundler & Co., Inc., mine and mill near Tres Piedras, Taos County, crude perlite production in New Mexico was about 40 percent of the national total. A third major producer entered the field in 1953 when the United States Gypsum Co. began operation of its mine north of Grants, Valencia County. Great Lakes Carbon Corp. opened a second large open pit mine at No Agua Mountain on property adjoining that of the Schundler Co. in 1957. Beginning in that year, New Mexico assumed the lead as the principal producing State in the Nation. The bulk of current production is from northwestern Taos County where the Great

Lakes Carbon Corp., Johns-Manville Perlite Corp. (successors since 1959 to F. E. Schundler & Co., Inc.), and United Perlite Corp. are active. The remainder is from U.S. Gypsum Co.'s mine near Grants. The Socorro mine and plant of the Great Lakes Carbon Corp. were closed early in 1961 with consolidation of the company's operations at No Agua Mountain. Minor past production has come from deposits southwest of Lordsburg, Hidalgo County, and south of White Signal, Grant County.

Annual production figures are listed below, based on quantities of crude perlite sold or used. The years from 1949 through 1953, taken from *Annual Reports of the State Inspector of Mines,* are on a fiscal year basis ending June 30 of each year; the years from 1953 through 1963, taken from annual volumes of *Minerals Yearbook,* are on a calendar year basis :

Year	Short tons	Year	Short tons
1949 [1]	7, 200	1956	167, 705
1950 [1]	17, 244	1957	187, 259
1951 [1]	46, 566	1958	202, 046
1952 [1]	68, 345	1959	240, 642
1953 [1]	60, 846	1960	240, 593
1953	84, 891	1961	245, 654
1954	111, 040	1962	258, 164
1955	147, 805	1963	259, 113

[1] From annual reports, State Inspector of Mines.

Most of the perlite produced is shipped as crude, sized aggregate to expansion plants located in marketing areas outside the state. Small amounts are expanded locally for filter aids, oil well cements, drilling mud additives, and other expanded aggregate uses. High shipping costs, bulky character, and subjection to damage in transit normally preclude shipping expanded perlite aggregates to distant markets.

Perlite deposits of developed or potential commercial value are widely distributed in western New Mexico, as shown in figure 62. The distribution is closely related to that of prominent volcanic fields of rhyolitic composition at or near eruptive centers. Available analyses indicate that volcanic glasses of perlitic type in New Mexico are prevailingly rhyolites of high silica content (table 44). All known deposits are Tertiary or early Quaternary in age.

TABLE 44.—*Chemical analyses of perlite and related volcanic glasses in New Mexico (recalculated to anhydrous basis)*

	Obsidian nodules percent [1]	Porphyritic perlite percent [2]	Pumiceous perlite percent [3]	Typical perlite percent [4]	Perlitic pitchstone percent [5]
SiO_2	76. 80	76. 42	76. 14	76. 68	76. 46
Al_2O_3	12. 39	13. 07	12. 66	13. 36	12. 90
Fe_2O_3	. 41	. 50	. 78	. 31	. 67
FeO	1. 00	. 44	. 31	. 50	. 33
MgO	Trace	. 23	. 14	. 04	. 21
CaO	. 40	1. 08	1. 12	. 54	2. 22
Na_2O	3. 50	3. 12	3. 24	3. 18	5. 08
K_2O	5. 28	4. 98	5. 37	5. 24	1. 97
H_2O-	. 05	. 36	. 26	. 14	3. 15
H_2O+	. 32	3. 70	3. 36	3. 60	5. 80

[1] Peralta Canyon, Jemez Mountains. R. C. Wells. analyst; U.S. Geological Survey Bull. 878, p. 35.
[2] Stendel deposit, Magdalena area. H. B. Wiik, analyst.
[3] Great Lakes Carbon Corp. mine, Socorro. H. B. Wiik, analyst.
[4] McDonald ranch deposit. H. B. Wiik, analyst.
[5] Leitendorf Hills (Pyramid Mountains) deposit. H. B. Wiik, analyst.

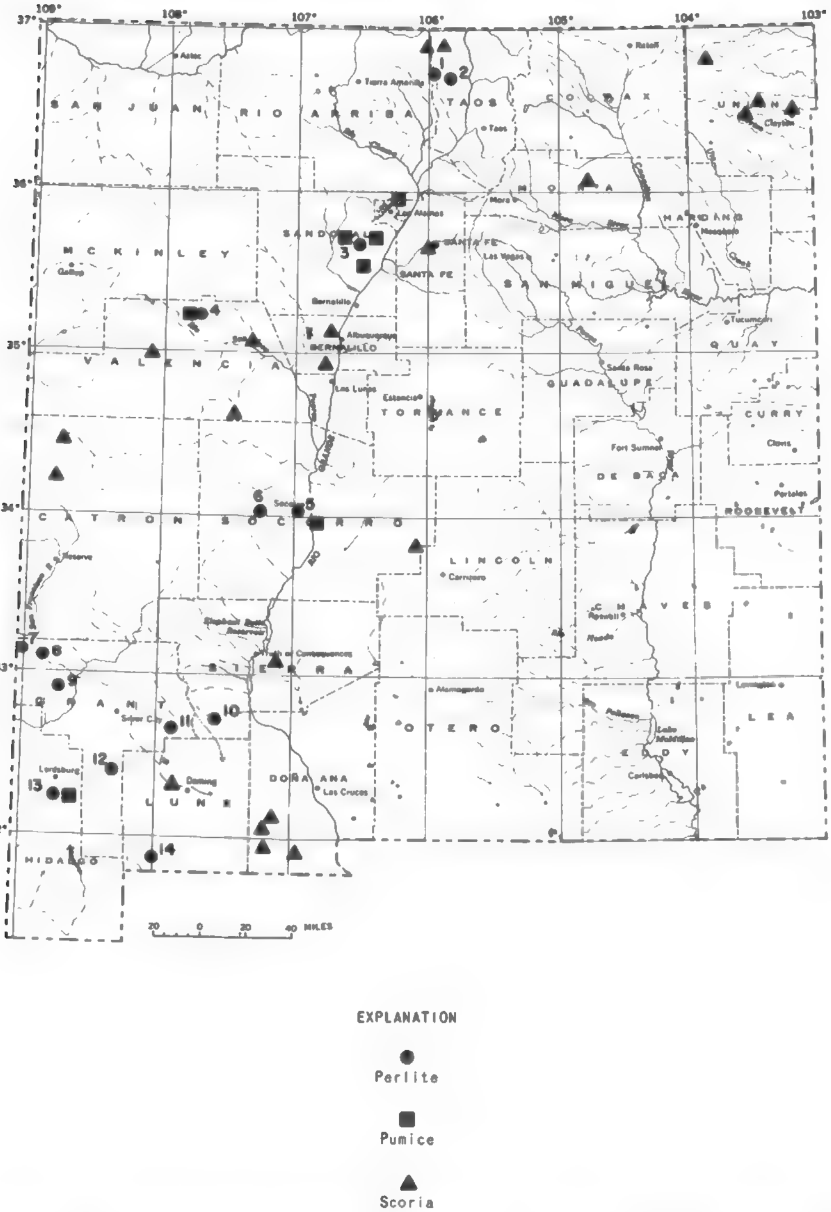


FIGURE 62.—Lightweight aggregates in New Mexico. (Numbers refer to localities discussed in text.)

All principal deposits lie west of the Rio Grande, extending from within 16 miles of the Colorado State line on the north to within 5 miles of the Mexican border on the south and westward to the Arizona State line (fig. 62). Brief summary descriptions of most of these have been provided by Weber *(in* Jaster, 1956, p. 386-389). Numerous other occurrences are scattered across this region, especially in the extensive volcanic tract from Socorro westward and southward. Most of these are not of current commercial interest because of their remote location, small size, excessive impurities, or high mining costs. The results of laboratory expansion tests of samples from many of these deposits are on file at the New Mexico Bureau of Mines and Mineral Resources in Socorro.

North-central New Mexico.—The principal developed resources of perlite in the State are at No Agua Mountain and southeast of Cerro de la 011a in northwestern Taos County (fig. 62, Nos. 1, 2). The geologic features and perlite deposits of this area have been described briefly by Weber *(in* Jaster, 1956, p. 388) and Schilling (1960, p. 19, 27,108-110).

No Agua Mountain is made up of a cluster of four hills of rhyolite whose structural relationships suggest extrusion as a volcanic dome or composite dome. No Agua dome, as well as others scattered across the Taos Plateau, is believed to have been erupted during the late stages of Pliocene and Pleistocene volcanism in the area. Several varieties of glassy and lithoidal rhyolite are present. Pale gray to buff, flow-banded, pumiceous perlite (nonperlitic) forms large masses of commercial grade that are easily mined by open-pit methods. According to Schilling (1960, p. 108), there are probably several hundred million tons of perlite of this class in the deposit.

Mining and milling of the northern part of the deposit, 7 miles north of Tres Piedras, was initiated in 1951 by F. E. Schundler Co., Inc. The Schundler property and plant were purchased by Johns-Manville Perlite Corp., the present operators, in 1959. The original Schundler plant was destroyed by fire in 1960 but was replaced by the year's end with a new one having an annual capacity of 150,000 tons. Products are transported 23 miles by truck to storage and rail-loading facilities at Antonito, Colo.

El Grande mine of Great Lakes Carbon Corp. is located on the southwestern side of No Agua Mountain, 1$^1/_2$ miles south of the Johns-Manville operation. Mining began in 1957, and the mill was activated in 1958. An expansion plant was completed at Antonito, Colo., in 1961 following termination of operations at the Socorro mine and plant. Loading and blending facilities are also located at Antonito.

A small mine on the eastern side of the No Agua deposit was operated for a short time by U.S. Perlite Co. but operations ceased in 1959. Several railroad cars of expanded perlite were shipped from Antonito, Colo., by that company in 1959, according to Schilling (1960, p. 110) .

A separate deposit, about 10 miles east-southeast of No Agua Mountain, is exposed in a group of hills that are similar in character, origin, and probable age to those of the No Agua deposit. Mining and milling of the perlite, which is reportedly similar to that at No Agua (Schilling, 1960, p. 110), has been conducted by United Perlite Corp. from early 1959 to the present. Crushed and sized crude perlite

is hauled 36 miles by truck to company loading and blending facilities at Antonito, Colo.

Commercial grade perlite occurs among the varied assemblage of volcanic glasses in the Jemez Mountains in Sandoval County. Among the more accessible localities of record (No. 3) are those on the southern slopes of the range in Cochiti, Bland, and Peralta Canyons, about 28 miles west of Santa Fe, and at Bear Springs, about 8 1/2 miles farther west (Weber, *in* Jaster, 1956, p. 387). The geology of the Jemez Mountains, a complex volcanic pile of Tertiary and Quaternary age, has been summarized recently by Ross and others (1961).

Pale gray to black ribs and dikelike masses of vitreous to pitchy volcanic glass are interlaced with rhyolitic breccias in Bland Canyon below the old mining camp of Bland. Both perlitic and nonperlitic varieties are present. Expansion tests revealed a favorable response from some samples, but commercial possibilities are limited by variations in character, the small size of individual masses of perlite, and limited exposures below a thick capping of massive welded tuff of the Bandelier.

Small segments of a mass of perlite in Peralta Canyon (sec. 29, T. 17 N., R. 5 E.) consist of pale gray perlitic to pumiceous perlite of commercial grade. Large parts of the body, however, contain interleaved flow bands of lithoidal rhyolite and perlite; hence, they are unsuitable as sources of commercial perlite.

Highly vitreous green to gray perlite in the vicinity of Bear Springs (secs. 29 and 32, T. 17 N., R. 4 E.) contains brecciated zones cemented with glass and lithoidal rhyolite and numerous zones that are altered and spherulitic. The results of fairly intensive exploration of these deposits subsequent to a cursory examination made in 1950 are unknown to the writer. Exploitation of the Bear Springs perlite has been handicapped by the prevalence of contained impurities and relatively remote location.

Only one deposit of commercial importance is recorded for northwestern New Mexico; it is located in East Grants Ridge about 8 miles northeast of Grants, Valencia County (No. 4). Although the area is at the southwestern edge of the Mount Taylor volcanic field (Hunt, 1938), the volcanic sequence was erupted from local vents rather than from the main center of Mount Taylor. Pumiceous tuff, felsitic rhyolite, obsidian, and perlite in East Grants Ridge are pierced by a basaltic neck and overlain by basaltic flows that form the cap rock of the ridge. The rhyolitic complex described by Kerr and Wilcox (1963) occupies an oval-shaped area about 1 by 1 1/9 miles. Potassium-argon determinations gave a calculated age of 3.3±0.3 million years for the rhyolitic assemblage (Bassett and others, 1963a, 1963b). The complex includes a central volcanic dome with a core of lithoidal rhyolite, a collar of obsidian and perlite, and a peripheral zone of pumiceous tuff within which, on the east, there is a partial ring of perlite separated from the central dome by tuff. Concentric inward-dipping flow bands in the perlite of the peripheral zone delineate a separate dome from that of the core. Flow-banded, pumiceous, gray perlite in the peripheral zone is similar to commercial perlites at No Agua and Socorro. Since 1953 it has been exploited by open-pit methods by U.S. Gypsum Co., whose crushing and sizing plant and railloading facilities are located in Grants.

Central New Mexico.—Occurrences of perlite and related volcanic glasses are common minor constituents of near-vent rhyolite assemblages in the Socorro, Chupadera, Magdalena, and San Mateo Mountains of Socorro County. Deposits near Socorro and Magdalena (Nos. 5, 6) have attracted attention as sources of commercial perlite, but only the Socorro deposit has been productive. The distribution and character of Cenozoic volcanic rocks in Socorro County were discussed by Weber (1963a).

The Socorro deposit of Great Lakes Carbon Corp. is at the southeastern edge of the Socorro Mountains about 3 miles southwest of Socorro (Weber, in Jaster, 1956, p. 388 ; Weber, 1963b) . Prominently flow-banded, pumiceous, pale gray to buffish-gray glass of rhyolitic composition (analysis 3, table 44) makes up a body having the form of a volcanic dome with exposed dimensions of about 2,000 by 2,600 feet and an exposed vertical extent of more than 450 feet. Vitric breccias and tuffs composed largely of the same pumiceous perlite overlap the north and south margins, whereas east and west margins are formed by high-angle normal faults. Similarities in physical character and mode of origin with the No Agua and Grants pumiceous perlites are noteworthy. Potassium-argon age determinations were inconsistent at 23.7 and 33.2 million years (Weber and Bassett, 1963).

The deposit was mined by open-pit methods by Great Lakes Carbon Corp. from 1949 to 1961. During that period, it was one of the principal domestic sources of perlite. Very large reserves of cheaply mineable perlite still remain. A crushing, sizing, and drying plant, together with rail-loading facilities, was located about one-half mile from the mine. The bulk of the product was shipped as size-graded crude, but smaller amounts were expanded at the plant for use as filter aids, oil-well drilling mud additives, and oil-well cement aggregates.

Perlite, vitrophyre, and vitric breccia are relatively widespread in the belt Of rhyolitic eruptives that extends southward and southwestward from Magdalena Peak, about 1¾ miles south of Magdalena (Weber, 1963a, p. 140). Attempts at commercial development of the deposits of this area have to date proved unsuccessful, due at least in part to variations in quality, the prevalence of excessive impurities, and high mining costs. At the Stendel deposit, about 6 miles south of Magdalena, a tabular body of porphyritic gray perlite of rhyolitic composition (analysis 2, table 41) with a thickness of approximately 200 feet and a mapped linear extent of more than one-half mile, is interbedded with a sequence of rhyolite flows, tuffs, and thin vitrophyres (Weber, *in* Jaster, 1956, p. 388; Weber, 1957). Zones of abundant spherulites and of montmorillonitic and zeolitic alteration impair the commercial possibilities of the deposit. Potassium-argon age determinations averaging about 14.3 million years (late Miocene) have been obtained from this perlite (Weber and Bassett, 1963).

Southwestern. New Mexico.—A number of occurrences are scattered across extensive volcanic tracts in Sierra, Catron, Grant, Luna, and Hidalgo Counties. A few of those that have received at least cursory examination are shown in figure 62 (Nos. 7-14). Although sporadic attempts have been made to develop several of the deposits commercially, mining operations have been short lived, and only small amounts of perlite have been marketed. The remote location and high costs

of transportation have largely discouraged development in much of this region.

Perlite and related volcanic glasses are associated with several rhyolitic vent complexes in northwestern Grant County (Nos. 7, 8, 9). Local masses of perlite, interlayered with flow-banded, spherulitic rhyolite, cap a series of small peaks along the Arizona-New Mexico State line west of Mule Creek, extending northward for several miles from New Mexico State Highway 78. These rocks were assigned to an upper rhyolite assemblage that locally interfingers with volcanic conglomerates and sandstones correlated tentatively with the Gila Conglomerate (Weber and Willard, 1959). A potassium-argon determination on obsidian nodules from the perlite gave a calculated age of 18.6 million years (middle Miocene) (Weber and Bassett, 1963). A correlative sequence that includes conformable tabular bodies of perlite makes up the main mass of the Mule Mountains a few miles east of Mule Creek. Other areas of outcrop have been noted in the Mogollon Mountains along the canyons of Iron Creek and the West Fork of the Gila River, 14 to 15 miles east of Mogollon. An area of upper rhyolite containing appreciable amounts of perlite is shown by Elston (1960) in a northwesterly trending belt about 1 mile wide and 8 miles long located 10 miles west and southwest of Cliff.

Perlitic phases are a minor constituent of rhyolitic flows and associated pyroclastics in several areas west of Lake Valley, western Sierra County (No. 10). The largest deposit, as described by Jicha (1954, p. 80), is a sill about 40 feet thick, with overburden of 100 to 200 feet, and an areal extent of 3 or 4 square miles. This area may include outcrops noted by Weber (in Jaster, 1956, p. 388) of an irregular flow sheet of gray to bluish-gray perlitic glass overlain by flow-banded felsitic rhyolite and underlain by rhyolitic tuffs and breccias. The upper part of the perlite is at least locally contaminated by spherulitic and lithoidal bands.

Perlite occurrences of doubtful commercial value in the Dwyer quadrangle (No. 11), which adjoins the Lake Valley quadrangle on the west, have been described by Elston (1957, pp. 72-73). Modes of occurrence here include bases of flows, margins of intrusive bodies, dikes, breccias, and lenses in tuff.

Perlite deposits on the McDonald ranch and vicinity (No. 12) crop out continuously for 6 miles along Burro Cienega in the northeastern part of T. 22 S., R. 15 W., and southeastward in isolated patches into the center of T. 22 S., R. 14 W. (Weber, *in* Jaster, 1956, p. 388 ; Ballmann, 1960, pp. 16-18). The main body has a tabular form up to 100 feet in thickness. Several textural and color varieties are present, but most are highly perlitic and of various shades of gray. Analysis 1, table 44, represents a highly perlitic variety. Spherulitic and lithoidal rhyolite bands and layers are intercalated with the perlite at several levels, locally reaching a thickness of more than 100 feet. Perlite was mined during 1953 from an isolated eastern segment of the deposit by El Paso Perlite Co., Inc. Expanded perlite aggregate was being produced at Gage, Luna County. The prevalence of altered zones and masses of lithoidal rhyolite in the deposit may have contributed to its subsequent abandonment.

A separate deposit to the northwest (sec. 8, T. 20 S., R. 16 W.) in Thompson Canyon has been described by Ballmann (1960, pp. 16-17)

as the Brock perlite. The character of the deposit suggests a highly fractured and faulted perlite dome about 4,000 feet wide and 2,000 feet thick. Many of the joints in the perlite are filled with quartz veins.

Massive brownish-red to dark-green perlitic pitchstone forms bold outcrops up to 500 feet high in the Leitendorf Hills (No. 13), about 8 miles south-southwest of Lordsburg (Weber, *in* Jaster, 1956, p. 387; Flege, 1959, pp. 16-17, 29, 31). As shown by Flege, the deposit crops out for nearly 2 miles in length, from one-half mile to a few hundred yards in width, has an exposed area of about 1 square mile, and an estimated volume within this area of 30 million cubic yards. The form is suggestive of a volcanic dome, but emplacement may have been by laccolithic intrusion. Irregular lenses and seams of devitrified glass and alteration products are prevalent. The composition (analysis 5, table 44) indicates a sodic rhyolite with a water content in the pitchstone range. A small, intermittent production of perlite came from this deposit during 1950-53. Selective mining was necessary because of the distribution of nonexpansible impurities. Expanded perlite aggregate was produced in a kiln operated by Kirk's Perlite Industries at Lordsburg.

Perlitic pitchstone, similar in physical properties to that near Lordsburg, is poorly exposed in low hills about three-quarters of a mile north of Hermanas station, Luna County (No. 14). Widespread devitrification of the glass and the prevalence of bands of lithoidal rhyolite are unfavorable for commercial development of this deposit (Weber, *in* Jaster, 1956, p. 387). Other larger perlitic bodies may, however, occur locally in the belt of rhyolite pyroclastics as mapped by Bromfield and Wrucke (1961), that extends for more than 20 miles to the northwest. The prevalence of agate-filled spherulites (thunder eggs) in this area suggests the former abundance of volcanic glass that has been altered and devitrified.

Resource potential.—As may be inferred from the foregoing discussion, New Mexico is amply supplied with developed reserves of commercial-grade perlite for a number of years of production at current rates. Total resources are extensive and many deposits remain untouched because existing economic factors preclude their profitable exploitation.

PUMICE

Pumice is a highly cellular, light-colored volcanic glass that is usually rhyolitic in composition. It occurs as fragmental aggregate in which individual particles range from coarse sand size to blocks several feet in diameter. Pumicite differs from pumice in being fine-grained and consisting largely of angular and curved particles (shards) of the shattered vesicle walls of pumice. It is one of the common varieties of volcanic ash. Industrial usage of the terms "pumice" commonly is extended to include dark-colored, cellular fragmental rocks of andesitic to basaltic composition, for which a separate designation as scoria or volcanic cinders is preferable. The more restricted usage is followed herein ; scoria is discussed separately.

Current use of pumice is principally as a natural lightweight concrete aggregate. Smaller amounts are used in scouring and cleaning compounds, as abrasives, soil conditioners, pozzolanic concrete addi-

tives, and for a host of minor purposes (Mielenz and others, 1951; Chesterman, 1956; Bates, 1960, pp. 40-44; Otis, 1960a). Pumicite can be used for most of the same purposes as ground pumice and offers some advantages for use as a carrier for insecticides and as a pozzolan.

Pumice is a product of explosive volcanism when expansion of magmatic gases in hot, plastic, fragmental ejecta causes rapid vesiculation. If quickly chilled, the particles retain their cellular texture and a resultant apparent specific gravity of less than 1.0. Deposits may be massive or stratified, depending upon the mechanics of eruption, the influence of deposition in subaerial and subaqueous environments, and modifications resulting from reworking by water and wind (Chesterman, 1956 ; Bates, 1960, pp. 39-50). The deposits include ash-fall and ash-flow tuffs, tuff breccias, and reworked volcanic sediments. Because of its tendency to denitrify with time and the ease of alteration by several geologic processes, commercial-grade pumice is restricted to deposits of Tertiary and Quaternary age.

The United States is among the major producers of pumice. Imports largely from Italy and Greece, have proved competitive with domestic products, especially on the eastern seaboard. High-quality abrasive grades are largely of Italian origin. Pumice and pumicite sold or used by producers in the United States in 1962 totaled 509,000 short tons valued at $3.2 million. This was considerably below the 1961 total of 936,000 tons and the 1953-57 average of 884,000 tons (Hartwell, 1963). Sources of pumice in this country are limited to the Western States. Deposits of pumicite extend into the central plains states, as a result of wind drift from volcanic sources to the west.

New Mexico has been a leading producer of pumice aggregate for a number of years. Production figures are difficult to compare at the state level because of differing bases of reporting and lumping of combined totals for pumice, pumicite, and scoria in some reports. Pumice production in New Mexico in 1963 was reported to have been 172,495 cubic yards valued at $311,947 (State Inspector of Mines, 51st Ann. Rept., 1964). Using Clippinger 's (1946, p. 14) figure of about 850 pounds per cubic yard for loose, dry, pit-run pumice from the Jemez Mountains area, this would amount to about 73,300 short tons. Annual production from 1950 to 1954 ranged from 148,900 to 524,500 tons; from 1955 to 1962, it ranged from 132,800 to 444,000 cubic yards (State Inspector of Mines, Ann. Repts.). Pit-run pumice generally is crushed, sized, and graded in small plants to required specification prior to shipment to consumers. The principal use has been in the manufacture of lightweight concrete building blocks in New Mexico and adjacent states.

Pumice and associated pumicite are widely distributed in western New Mexico, but the major part of the state's resources is in the southern and eastern slopes of the Jemez (Valles) Mountains in Sandoval, Santa Fe, and Rio Arriba Counties (fig. 62). Deposits extend from north of Jemez eastward to Cochiti and northward to a few miles west of Espanola. The pumice occurs in friable beds of pumiceous lapilli tuff generally 8 to 20 feet thick (locally up to 70 feet) and has little or no overburden in many parts of this area (Clippinger, 1946, pp. 13-14; Clippinger and Gay, 1947, p. 37). The pumice beds comprise the lower member of the Bandelier Tuff of Pleistocene age (Ross and others, 1961, p. 141; Elston, 1961, p. 164). Deposition of both the

lower and upper members of the Bandelier Tuff resulted from eruption of turbulent ash flows from centers in the crest of the Jemez Mountains (Ross and Smith, 1961). The upper member, however, was indurated and welded and consequently is valueless as a source of commercial-grade pumice. This area has been the chief source of pumice aggregate for a number of years, with as many as seven mines in production during peak periods. According to Elston (1961, p. 164), reserves are inexhaustible.

Pumiceous lapilli tuffs in East Grants Ridge, about 5 miles northeast of Grants, Valencia County, were formerly a source of high-quality abrasive pumice. During the period from July 1946 to July 1952, a total of 59,473 short tons of pumice concentrate was produced from open-pit operations of Pumice Corp. of America (State Inspector of Mines, Ann. Repts.). The tuff consists of lapilli and blocks of pumice, rhyolite, and exotic rock fragments in a matrix of white ash (Kerr and Wilcox, 1963, p. 209). Separation of the pumice from associated impurities was made by gravitational methods in a mill at the mine. Large reserves remain in the deposit. Similar pumiceous tuffs in adjacent areas have been described by Hunt (1938, pp. 58-60).

Elsewhere in the State, there has been little development of commercial deposits. Scattered lenses of water-laid lump pumice and pumicite are poorly exposed in low bluffs adjoining the Rio Grande from about 3 miles east-northeast of San Antonio southward to beyond Fort Craig, Socorro County. The quality of lump pumice in these occurrences is comparatively low. Bedded pumiceous tuff about $4^1/_2$ miles northwest of Magdalena, Socorro County, has apparently yielded small test lots of rather impure pumice. A deposit south of Lordsburg was a source of small amounts of pumice aggregate mined by Kirk's Perlite Industries in 1950.

SCORIA

Scoria is a cellular, dark-colored volcanic rock of basic composition (commonly basalt or basaltic andesite). In industrial usage, scoria is also known as volcanic cinders or, misleadingly, as pumice. In addition to compositional differences, scoria differs from pumice in its darker color, higher density, coarser vesicles, more crystalline texture, and generally higher strength. Uses include natural lightweight concrete aggregate, road surfacing aggregate, and railroad ballast. As a constituent of lightweight concrete, scoria characteristically provides less weight reduction accompanied by higher strength than pumice. A cubic yard of crushed scoria weighs from 1,000 to 1,500 pounds (Clippinger, 1946, p. 8).

Commercial deposits of scoria are products of the explosive eruption of basaltic lavas. Vesiculation due to the rapid expansion of water vapor takes place while clots of fluid lava are in flight. Deposition of the pyroclastic aggregate is usually concentrated peripherally around the vent resulting in the development of a cinder cone.

Production of scoria in the United States has risen rapidly in recent years from an average of 738,000 short tons annually from 1953 to 1957 to 1,738,000 tons valued at $3.1 million in 1962 (Hartwell, 1963). An unknown additional amount is used but not marketed and is unrecorded.

Scoria is more widely distributed than pumice in New Mexico, as is shown by figure 62, which includes only a few of the numerous deposits.

Recorded production in 1963 was 186,046 cubic yards valued at $342,358 (State Inspector of Mines, 51st Ann. Rept., 1964). Production was reported for five counties, with Union County contributing more than 86 percent of the total, followed in decreasing order by Dona Ana, Bernalillo, Santa Fe, and Lincoln. Twelve mines were registered during the year. Production has shown a progressive downward trend in years subsequent to the high of 574,365 cubic yards reported for 1958 (fiscal year ending June 30, 1958; State Inspector of Mines, Ann. Repts.). Most of the deposits are in cinder cones of Quaternary age. Resources are exceedingly large. The physical characteristics of scoria from a number of deposits in the State, and the results of tests of concrete mixes made with scoria aggregates, have been described by Clippinger (1946, pp. 15-24).

EXPANSIBLE SHALE

Some clays, shales, and slates when rapidly heated to temperatures in the vitrification (glass-forming) range will expand or bloat due to expansion of gases. The resulting product is a glassy, cellular, lightweight aggregate with properties somewhat similar to those of scoria. The expansion process is usually carried out in a rotary kiln at temperatures preferably in the range of 1,800° to 2,200° F. (Conley and others, 1948; Riley, 1951; Hamlin and Templin, 1962).

Expansible shales are widely used as lightweight concrete aggregates in the United States. Because of the ready availability of raw materials in many areas, they offer competitive advantages over natural lightweight aggregates which must be shipped in from distant sources. The consumption of shales and clays for this purpose in the United States in 1962 was 6,769,912 short tons (de Polo and Brett, 1963, p. 439) .

Little is known about the distribution of expansible shales and clays in New Mexico inasmuch as natural aggregates in this area provide more economical sources. However, there are undoubtedly large resources of suitable materials in many areas of the State. Tests of samples of Mancos Shale from the Shiprock area, San Juan County, were reported to be encouraging (Allen, 1955).

VERMICULITE

Vermiculites are a group of micaceous hydrous silicates that expand by exfoliation along cleavage planes when rapidly heated. The expanded product is a lightweight aggregate with excellent heat and sound insulating properties.

The principal uses are lightweight plaster aggregate, loosefill insulation, and for horticultural purposes (North and Chandler, 1953; Myers, 1960; Otis, 1960b). Production in the United States in 1962 was 205,000 short tons of crude vermiculite with an average value of $16.06 per ton ; exfoliated vermiculite production was 152,000 short tons with an average value of $73.37 per ton (Hartwell and Jensen, 1963). The bulk of the production in the United States has been by one producer in Montana.

Commercial-grade deposits of vermiculite are unknown in New Mexico, although mineralogical occurrences are not uncommon. Northrop (1959, pp. 549-550) cites occurrences in Grant, Mora, Rio Arriba, and San Miguel Counties. A plant in Albuquerque produces exfoliated vermiculite from raw material shipped from Montana.

LIMESTONE AND DOLOMITE

(By F. E. Kottlowski, New Mexico Bureau of Mines and Mineral Resources, Socorro, N. Mex.)

Limestone and dolomite are sedimentary rocks composed mainly of calcium and magnesium carbonate. They are abundant in many large areas throughout the United States, including New Mexico, but are sparse or absent in some regions. They are basic raw materials used in such diverse industries as construction, agriculture, manufacturing, and smelting.

All transitions exist in nature between pure limestone and pure dolomite. Terminology of rocks varying in composition between the two extremes of purity include magnesian limestone, dolomitic limestone, and limy dolomite. Common impurities include iron carbonate, iron oxide, chert, silica, clay, and carbonaceous matter. Most commercial users require rock with less than 20 percent impurities.

Both limestone and dolomite, and their mixtures, are used in two different ways : (1) for their bulk physical properties, for example, as crushed rock for roadbuilding, and (2) for their chemical properties. Uses of limestone and dolomite for their chemical properties vary with the relative content of calcium and magnesium.

High-calcium limestone is used by industry as a source for lime and as a raw material in the production of cement, paper, glass, alkalies, calcium carbide, and metallurgical flux. High-calcium limestone contains at least 95 percent calcium carbonate with specified limitations on impurities such as magnesium carbonate, alumina, silica, sulfur, iron oxide, and phosphorus.

Cement rock is a low-magnesium limestone containing clay, silica, and iron oxide. A few impure limestones contain a proper natural mixture of these materials and can be used directly to manufacture portland cement. A typical analysis of cement rock (Jacksonburg Limestone of the Lehigh Valley, Pennsylvania) is : $CaCO_3$ 72percent, $MgCO_3$ 4 percent, Al_2O_3 5 percent, Fe_2O_3 2 percent, and SiO, 17 percent. In most cement plants, the correct combinations of limestone, shale, quartz sand (if necessary), and iron oxides are brought together to produce cement. Gypsum is added to control the set of the cement. The Ideal Cement Co. plant at Tijeras about 10 miles east of Albuquerque, for example, quarries limestone and shale from Pennsylvanian strata near the cement plant, and hauls iron ore and gypsum from deposits in Socorro County and Sandoval County, respectively. Only small percentages of these latter two minerals are used ; the shale contains some quartz silt and provides the alumina and silica.

The chief chemical products from dolomite are dead-burned dolomite, refractory magnesia, basic magnesium carbonate, and magnesium metal. Dead-burned and raw dolomite are used chiefly for the construction and repair of open-hearth furnace linings, and are comparatively low-price products that must be quarried and calcined as close to consuming plants as possible. Similarly, refractory magnesia should be prepared near consuming plants. Basic magnesium carbonate is used extensively to manufacture asbestos fiber insulation, and plants in the United States are located near such large consuming areas as California, Illinois, and New York. The silicothermal process is used to make magnesium metal from dolomite, but as this

process is more expensive than the electrolytic method utilizing sea water, silicothermal production has been used in the United States mainly during periods of national emergency.

Most limestone and dolomite in New Mexico was deposited in thick, extensive beds in ancient seas. Some of the younger limestones, mostly varieties of travertine, were precipitated in inland lakes, by springs, and as caliche that caps topographic surfaces. In mineralized areas, some dolomite has been formed by the replacement of calcium in limestone by magnesium carried in hot solutions. Veins of calcite, dolomite minerals, and aragonite (a variety of calcium carbonate) also are formed from natural hot solutions.

Small crude lime kilns were built by Spanish settlers some centuries ago in north-central New Mexico to obtain whitewash and lime mortars. Local lime kilns were used in many areas until centralization and automation of the lime industry after World War I. In 1910-12, limestone was quarried in eight counties and more than 4,400 tons were produced, being used in the manufacture of lime and cement and as railroad ballast. Kilns were in operation near Silver City, Watrous, in Mora County, Kirtland in San Juan County, Las Vegas, Santa Fe, and near Bluewater in Valencia County. Other quarries were being worked near Vaughn, Tecolote in Lincoln County, Cerrillos in Santa Fe County, on Cerro de Muleros in Dona Ana County and near Alamogordo (Burchard, 1912, 1913).

In contrast, during 1920, only 660 tons of lime were produced in the State (Loughlin and Coons, 1923) while 2,400 tons were transported from Texas and Colorado. That year 1,134 tons of limestone building stone were quarried and sold ; thereafter, the sale of limestone for building stone and "onyx marble" decreased to a small part of the annual average of building stone quarried in New Mexico. Until the installation of the Ideal Cement Co. quarry and cement plant at Tijeras in 1959, most cement and other lime products used in the State were shipped in from Colorado, Texas, and Arizona.

Use of limestone as a source of lime depends upon future development and acquisition of industry in New Mexico. At present, crushed and ground limestone, caliche, and some travertine are used locally as a soil conditioner. The Chino Mines Division of Kennecott Copper Corp. quarries Pennsylvanian limestone from Lone Mountain west of Hurley. This limestone is calcined in a kiln at Hurley, about 35,000 tons of hydrated lime being produced each year and used for neutralization of the flotation circuits in the Hurley mill. Some limestone is used as a conditioning agent in various mills in New Mexico and in adjoining areas. Ground limestone is applied as a dust to the walls of coal mines in the northern part of the State to reduce fire hazards. The largest use at the present time is as crushed stone for concrete aggregate, road metal, railroad ballast, sewage filter beds, and roofing granules. Limestone is a monomineralic rock and has much more uniform weathering characteristics than other common rocks, such as impure sandstone, granite, basalt, rhyolite, and andesite. Most limestone, therefore, is a more resistant rock for road metal or concrete aggregate.

In 1962 the United States ranked first in world production of cement with 346 million barrels (376-pound barrels) followed by the U.S.S.R. with 336 million barrels. New Mexico's production of

cement was one of the lowest of the States that have cement factories. New Mexico's production of lime during 1962 was 28,969 tons, also among the lowest of the lime-producing States. The national production of lime was 13.7 million tons, ranking second in the world behind U.S.S.R.'s 19 million tons.

Carbonate rocks occur in most parts of New Mexico as shown on figure 63. Most of the high-purity dolomites (Kottlowski, 1957) occur in southern New Mexico; whereas limestones crop out or are near the surface in about one-fourth of the entire State. They range in age from Cambrian to Cenozoic. Some of the high-calcium limestones of Mississippian, Pennsylvanian, Permian, and Early Cretaceous ages exceed 100 feet, and locally even 1,000 feet in thickness.

High-calcium limestone samples have been collected (Kottlowski, 1962) from Cenozoic travertine of the Mesa del Oro and Ladron Mountains areas; the Tertiary algal limestone of Apache Valley in the southwest part of the Caballo Mountains; Lower Cretaceous limestone of southwestern New Mexico ; Upper and Lower Permian limestone of the Guadalupe, Sacramento, Robledo, Florida, and Oscura Mountains; Pennsylvanian limestone of the Sandia, Sangre de Cristo, Sacramento, Ladron, Magdalena, Oscura, Franklin, and Hueco Mountains, Cerros de Amado, and near Luna ; and Mississippian limestone of the Sacramento, Tres Hermanas, and Peloncillo Mountains. Selective quarrying may yield high-calcium limestone from the Todilto Limestone of Jurassic age southeast of Grants, from erratic local deposits of Cenozoic travertine and caliche throughout the State, and from the El Paso Limestone of Ordovician age in southwestern and south-central New Mexico.

Most of the high-calcium limestones in New Mexico are of Paleozoic age and mainly of late Paleozoic (Mississippian through Permian) age. Most of the dolomites, in contrast, are of early Paleozoic (Ordovician and Silurian) age, although some of the Permian units are made up of dolomite and dolomitic limestone. Locally, limestone of the Todilto is high in calcium. The Lower Cretaceous beds of southwestern New Mexico include high-calcium limestone, but limestone from Upper Cretaceous beds (throughout central and northern New Mexico) contains at least 10 percent impurities. Cenozoic caliche and travertine are impure except for local high-purity lenses such as the algal limestone in the Tertiary Palm Park Formation of Kelley and Silver (1952), a high-calcium limestone in the Caballo Mountains.

LIMESTONE

Northwestern New Mexico.—In northwestern New Mexico, limestone occurs in the Mississippian and Pennsylvanian Systems, in the Permian Yeso Formation and San Andres Limestone, in the Jurassic Todilto Limestone and Upper Cretaceous sequence, and as travertine and calcareous tufa, of Cenozoic age. Carbonate rocks in the Yeso Formation of this area are mostly dolomitic and silty and are not shown on the outcrop map although they could be used as crushed stone. Limestone in the San Andres Limestone of the Zuni Mountains and Lucero Mesa areas is chiefly cherty, arenaceous, or dolomitic. Limestone beds of Late Cretaceous age are within sequences of dark marine shale, such as the Mancos Shale; they are highly argillaceous

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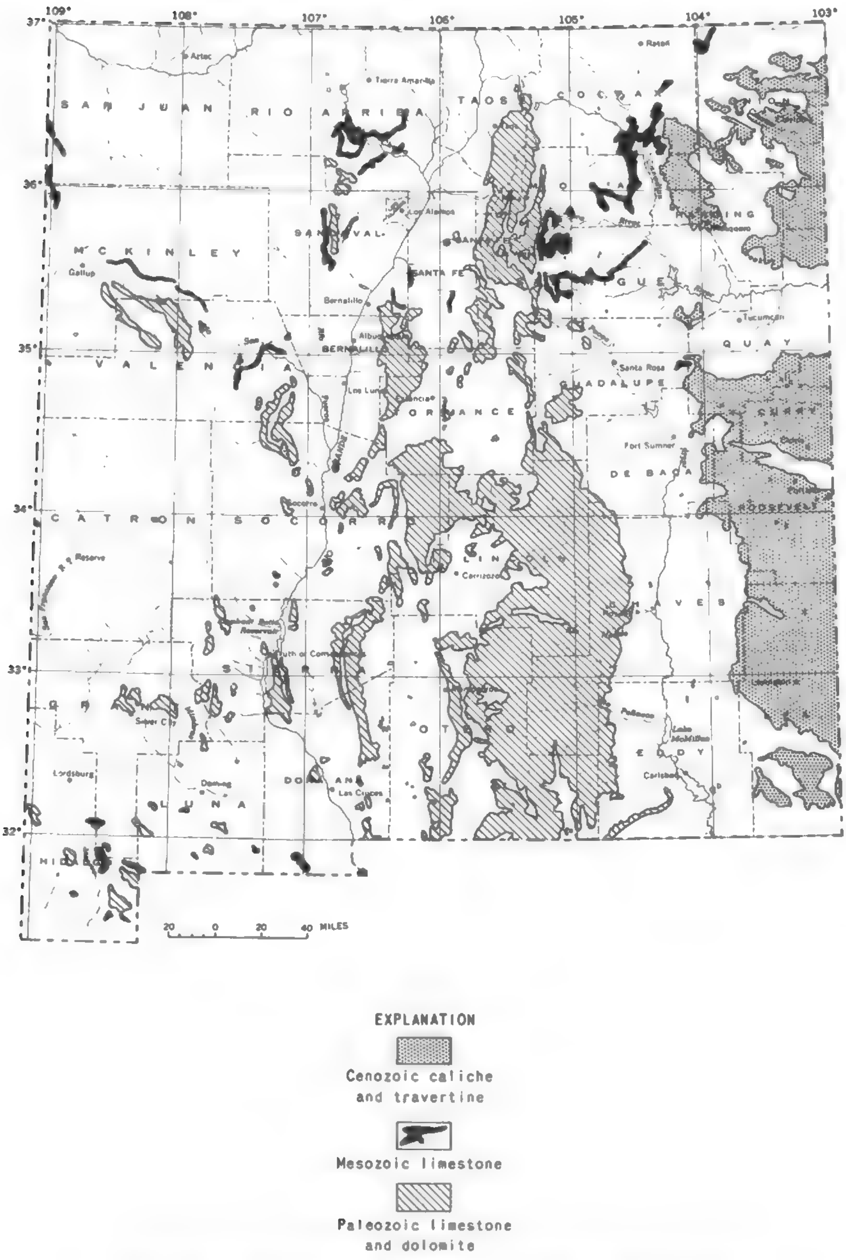


FIGURE 68.—Limestone, caliche, and dolomite in New Mexico.

and their outcrops are not shown. Some of this impure limestone, however, has been used near Farmington to make lime.

Along Arroyo Colorado Valley within the Laguna Indian Reservation of northwestern Valencia County, limestone in the Todilto Formation is 15 to 40 feet thick and caps extensive benches. Locally, the main part of the limestone contains as much as 94 percent $CaOO_3$. Northwest of Gallup, the limestone is 5 to 14 feet thick but contains about 12 percent silica.

Lucero Mesa and the nearby mesas of northwestern Socorro County and adjoining parts of Valencia County are isolated but contain thick limestone beds in the San Andres Limestone and within the Pennsylvanian System. Much of the limestone is impure but some of the Pennsylvanian limestone is high in calcium. Travertine and calcareous tufa spring deposits are extensive along the fault zones bordering some of these mesas; these Cenozoic limy rocks are being quarried as travertine "marble." Their purity varies greatly ; most of the travertine contains 15 percent impurities but some lenses are of high-calcium grade.

Mississippian and Pennsylvanian limestone units, some high in calcium, crop out on the west edge of the Ladron Mountains. To the west is an extensive plain underlain by Cenozoic travertine; analyses of some of the purer lenses indicate 99 percent $CaCO_3$. These deposits are relatively inaccessible and are reached by ranch roads 17 to 25 miles from Interstate Highway 25 at Bernardo.

North-central New Mexico.—Limestone from the Mississippian and Pennsylvanian Systems, from the Yeso Formation, and from the San Andres Limestone in the Nacimiento Mountains area is mostly arenaceous and cherty. Limestone from the Todilto Formation is impure and only 1 to 12 feet thick near the Nacimiento Mountains and to the north. In central Rio Arriba County, the limestone beds in the Mancos Shale reach a maximum thickness of only 3 feet and are highly argillaceous.

Mississippian limestone units in the northeast part of the Sandia Mountains are as much as 75 feet thick and include some high-calcium limestone. The thick limestone units in the Pennsylvanian System form extensive dip slopes in the east parts of the Sandia and Manzano Mountains. These are the limestone beds quarried, along with interbedded shale, near Tijeras by the Ideal Cement Co. Much of the Pennsylvanian limestone is arenaceous or cherty, but some contains more than 95 percent $CaCO_3$. Limestone in the Yeso Formation, San Andres Limestone, and Todilto Limestone of this area is thin and impure.

Pennsylvanian rocks cover large areas of the Sangre de Cristo Mountains and are underlain in many areas by Mississippian beds; both sequences contain numerous limestone beds that range widely in purity. Quarries have been operated in these limestone beds near Santa Fe, Las Vegas, and Taos. Thin impure dolomitic limestone beds occur in the Yeso Formation and San Andres Limestone south and east of the Sangre de Cristo Mountains on Glorieta Mesa and in the foothills south of Las Vegas. The Todilto Limestone crops out in local areas near Lamy, Santa Fe County, and caps a bench along the steep slopes of the Canadian Escarpment extending eastward to and beyond the Canadian River Canyon. Limestone in the formation is impure and only 5 to 15 feet thick in this area, but it is the only limestone available in most of central and eastern San Miguel County.

Highly argillaceous, dark limestone occurs within Upper Cretaceous shale units m several synclinal areas near Galisteo, Cerrillos, and Madrid, as well as north and east of Las Vegas. This Upper Cretaceous limestone contains about 85 percent $CaCO_3$, and is too impure for high-calcium uses.

Northeastern New Mexico.—The northeast-trending belt of Upper Cretaceous outcrops in northeastern New Mexico contains relatively thick (20 to 40 feet) limestone units only in the Fort Hays Limestone Member of Niobrara Formation of eastern Colfax County and northwesternmost Union County, and the Greenhorn Limestone of northwesternmost Union County. Limestone beds of the Greenhorn southwest of Union County are too thin and too impure to be of much use except as a low-grade crushed stone. Similarly impure limestone of the Greenhorn crops out in a small block 22 miles southeast of Tucumcari. These limestone units range from 15 to 60 feet in thickness, and consist of limestone beds (85 percent CaCO3) averaging 18 inches thick separated by limy shale beds of similar thickness.

Eastern New Mexico.—Much caliche is used in eastern New Mexico as road metal. The caliche caps high surfaces cut on gravel of the Pliocene Ogallala Formation and underlies much of the High Plains area (fig. 63). However, the caliche varies greatly in thickness and in most places is impure. An average sample contains about 35 percent quartz sand and silt.

Central New Mexico.—Limestone in central New Mexico occurs within the Mississippian, Pennsylvanian, and Permian rocks and Mancos Shale. Cenozoic travertine and caliche is relatively sparse except near the Ladron Mountains. Mississippian limestone, mostly cherty, crops out in the Lemitar, Magdalena, and San Andres Mountains and Coyote Hills. Thick limestone units mark the Pennsylvanian sections of the region. Limestone units in the Yeso Formation are not shown on the map (fig. 63) as they are thin and impure.

The San Andres Limestone is 200 to 700 feet thick and crops out over large areas on Chupadera Mesa, Socorro County, Mesa Jumanes, Torrance County, the western flank of the High Plains west of the Pecos River, eastern dip slopes of Sierra Blanca and the Sacramento Mountains, western cuestas of San Andres Mountains, the high ridges east of Socorro, the Phillips Hills, and on Carrizozo dome. Many of the limestone beds include variable amounts of dolomite, and some are cherty and arenaceous. In general in this region, where the San Andres Limestone is 500 or more feet thick, it consists of a lower limestone and an upper dolomite.

Limy beds in the Mancos Shale are thin lenticular impure black limestone intercalated with black shale, but they have been used locally for crushed rock. They contain about 75 percent $CaCO_3$ and more than 15 percent combined silica and alumina.

Near Abo Pass between the Manzano Mountains to the north and Los Pinos Mountains to the south, Pennsylvanian limestone beds have been prospected by the Permanente Cement Co. Some of the limestone beds are high in calcium. Nearby are outcrops of shale, and gypsum is available from the Yeso Formation a few miles to the east. U.S. Highway 60, the Santa Fe Railway, and two gas pipelines cross the mountains at Abo Pass.

High-calcium limestone beds of Pennsylvanian and early Permian age crop out over large areas in the Oscura Mountains and Cerros de

Amado east of Socorro. Some of the noncherty beds contain 96 to 98 percent $CaCO_3$, are thick, almost horizontal, and cap extensive mesas where they could be quarried without removal of thick overburden.

Southwestern New Mexico.—Limestone occurs within the Cambrian and Ordovician Bliss Sandstone, Ordovician El Paso Limestone, Ordovician Montoya and Silurian Fusselman Dolomites, and Devonian, Mississippian, Pennsylvanian, Permian, and Cretaceous strata. Pre-Pennsylvanian sedimentary rocks thicken southward to about 4,000 feet near El Paso, Tex., and to 3,700 feet in the southwesternmost corner of the State. Most of the limestone in the pre-Mississippian sequence, however, contains magnesium and grades into dolomite.

The Lake Valley Limestone of Mississippian age exceeds 100 feet in thickness in the Cooks Peak, Lake Valley, southern Black Range, Silver City, and Santa Rita areas. The thicker, partly correlative Escabrosa Limestone is 500 to 1,000 feet thick in the Tres Hermanas, Peloncillo, Big Hatchet, and Animas Mountains and Klondike Hills. Selected samples of the purer beds contain at least 98 percent CaCO3.

Pennsylvanian rocks are 800 to 2,400 feet thick in the region and, except locally, are mainly limestone. Many of the mountain ranges are capped by Pennsylvanian limestone that forms extensive outcrops in the Fra Cristobal, Mud Springs, Caballo, Big Hatchet, and Peloncillo Mountains, Sierra Cuchillo, Black Range, and Silver City-Santa Rita areas. Much of the limestone is cherty but beds of high-calcium limestone are numerous.

The Hueco Limestone of Early Permian age crops out in the Florida and Tres Hermanas Mountains. The Pennsylvanian Horquilla limestone and the Pennsylvanian and Permian Earp Formation occur in the Big Hatchet, Animas, and Peloncillo Mountains. Some limestone in the Horquilla and Hueco contains 95 to 98 percent $CaCO_3$. In the parts of southwestern New Mexico where the Permian Yeso Formation and San Andres Limestone crop out, the contained limestone appears to be dolomitic or impure.

Lenticular, black, argillaceous limestone occurs in the Mancos Shale of the Caballo and Fra Cristobal Mountains area and in the Colorado Shale near Cooks Peak, and in the Silver City-Santa Rita area. The Lower Cretaceous sequence that occurs in southern Dona Ana, southern Luna, southern Grant, and southern and central Hidalgo Counties includes thick fossiliferous limestone units, many of which are high in calcium.

Impure caliche caps many of the extensive surfaces of this semiarid region ; samples analyzed contain at least 29 percent insoluble residues. High-calcium algal limestone occurs in the Tertiary rocks of the southwestern Caballo Mountains area but it is far from transportation facilities.

South-central New Mexico.—The Sacramento and Guadalupe Mountains are largely underlain by limestone. West of the Sacramento Mountains crest, most of the limestone outcrops are of pre-Permian rocks; to the east, the outcropping limestone units are of Permian age, other than the caliche capping Llano Estacado. Pre-Mississippian formations thicken southward along the San Andres-Organ-Franklin chain of ranges to about 3,600 feet in the northern Franklin Mountains near the New Mexico-Texas State line. None of these ire-Mississippian units contains high-calcium limestone in this part of he State.

The Lake Valley limestone of Mississippian age is 60 to 400 feet thick in the San Andres and Sacramento Mountains, and its crinoidal beds contain 98 percent $CaCO_3$ in many areas. Near Alamogordo, the Lake Valley limestone has been quarried as "marble." Pennsylvanian rocks vary greatly in thickness and lithology throughout south-central New Mexico, but most areas contain much limestone, and high-calcium beds occur in parts of the sequence in the San Andres, Sacramento, Robledo, Organ, and northern Franklin Mountains.

Lower Permian rocks include much limestone. Some is high in calcium in the Robledo, Dona Ana, San Andres, Sacramento, Franklin, i and Hueco Mountains. The Yeso Formation is dominantly limestone in the south part of the Sacramento Mountains and on Otero Mesa. High-calcium limestone is present in the San Andres Limestone of the San Andres and Sacramento Mountains, although eastward, in the Guadalupe Mountains area, the entire formation is dolomitic or dolomite.

Upper Permian rocks of the Guadalupe Mountain and Pecos Valley area include many carbonate-rock beds but they are chiefly thin, impure, and dolomitic. Reef limestone of the Guadalupe Mountains ranges from dolomite to high-calcium limestone. Locally the reef complex is 1,500 to 2,000 feet thick and is several miles wide. It is exposed along the southeast front of the Guadalupe Mountains from near Carlsbad to south of the New Mexico-Texas State line.

Lower Cretaceous limestone beds crop out in the Potrillo Mountains and on Cerro de Muleros (El Cristo Rey) in southern Dona Ana County. Some of this limestone is high in calcium but there is much interbedded and intermixed clay and quartz sand. Limestone beds in the East Potrillo Mountains have been quarried for building stone, and those bordering Cerro de Muleros are used by the Southwestern Portland Cement Co., along with Cretaceous shale, at its cement plant in El Paso, Tex.

Southeastern New Mexico.—Caliche caps many of the older gravel surfaces of the Pecos Valley and elsewhere. Caliche is especially thick (up to 40 feet) as the "caprock" of the Llano Estacado, the High Plains east of the Pecos River. Local lenses may be of high-calicum limestone but most of this caprock contains 19 to 40 percent impurities and is used mainly for road metal throughout the plains area.

DOLOMITE

In addition to the vast amounts of limestone in New Mexico, there are large deposits of high-purity dolomite in the south-centra). part of the State, in the region from the Sacramento Mountains west to Deming, and from the north tip of the San Andres Mountains south to Mexico. Iron ore and silica sands, which could be used to make the ferrosilicon necessary to silicothermal production of magnesium metal, are present in large amounts in the same area. Natural gas is available as a source of power, there is an adequate pool of labor, and the warm climate would allow continuous operations.

The dolomite is mainly of early Paleozoic age and occurs in the El Paso (Ordovician) Limestone and Montoya (Ordovician) and Fusselman (Silurian) Dolomites in the Sacramento, San Andres, Organ, Robledo, Caballo, Mud Spring, Florida, Vittorio, Big Hatchet,

Peloncillo, and Franklin Mountains; at Bishop Cap, Sierra Cuchillo, Black Range, Cooks Peak, and Snake and Klondike Hills; near Lake Valley ; on the west side of the Mimbres River valley ; and near Silver City.

The El Paso Limestone is predominantly limestone, but in many areas thick beds and irregular masses have been dolomitized, and in some localities, such as the San Andres Mountains, most of the beds of the formation are dolomitic limestone or dolomite. The Montoya Dolomite in most places is almost entirely dolomite. Most of the high-purity dolomite of the Montoya occurs near the base of the formation (the Upham Member), although the lower part of the Montoya is highly arenaceous. The Aleman Cherty Member and the uppermost part of the Cutter Member are cherty and silty, respectively. Except where removed by post-Ordovician erosion, the Upham Member is 40 to 120 feet thick.

The Fusselman Dolomite is almost entirely pure dolomite except in localities where chert forms appreciable parts of some beds. The Fusselman thickens southward from a knife edge in the central part of the San Andres Mountains to nearly 1,000 feet in the Florida and southern Franklin Mountains. Millions of tons of high-purity Fusselman Dolomite that could be quarried inexpensively occur in the Sacramento, Robeldo, San Andres, and Florida Mountains.

Much of the upper part of the San Andres Limestone in the large area east of the crest of the Sacramento Mountains is dolomite and most of the formation in the Guadalupe Mountains is dolomite. Interbeds of dolomitic limestone are numerous, and many of the dolomite beds are siliceous. There are thick persistent beds of high-purity dolomite in the San Andres Formation on the west side of the Guadalupe Mountains.

SAND AND GRAVEL

(By W. D. Carter, U.S. Geological Survey, Washington, D.C.)

INTRODUCTION

Sand and gravel are so common that most people rarely consider them as mineral commodities, yet they constitute the largest volume of mineral raw materials produced from the earth. In the United States 822,120,000 tons of sand and gravel having a value of $848,757,000 were produced in 1963 (Cotter, 1964). That year New Mexico ranked 35th among the States in the production of sand and gravel with a total of 8.403,000 short tons having a value of $12,844,000. These were produced from 125 plants of which 81 were commercial businesses and 44 were State or Federal operations and their contractors. Approximately 75 percent of this production was gravel for paving by local, county, State, and Federal highway departments. Approximately 900,000 short tons of gravel went into construction of buildings, bridges and other structures. Sand production totaling slightly more than 1 million short tons was used mainly for building purposes. The average local price of sand and gravel was $1.53 per short ton as compared to the National average for 1963 of $1.03 (Cotter, 1964). This difference was probably due mainly to costs of transportation of raw material from the excavation to the construction site.

DESCRIPTION, USES, AND SPECIFICATIONS

Sand and gravel are unconsolidated rock fragments formed by the action of air and water on bedrock surfaces. Deposits may be mixtures of fragments from many types of rocks or, more rarely, they may be of a single rock type, depending largely on the size of the source area and the rock types exposed within it. Sands usually contain a high percentage of quartz and other resistant silicate minerals. A deposit may have coarse or fine-grained, angular, or rounded fragments that are poorly sorted or well sorted, depending on the relative hardness of the rock fragments and the mode of deposition.

Sand is usually defined as granular material 2 mm in diameter or less which passes through a No. 5 sieve but is predominantly retained by the No. 200 (74 micron) sieve. Gravel usually includes fragments that are larger than 2 mm in diameter. Wentworth (1922) classifies the coarse material as granule, pebble, cobble, and boulder gravel, in order of increasing size.

Sand and gravel are low-value, high-bulk commodities which generally must be mined close to areas of consumption to be profitable. Used mainly for construction purposes they serve as aggregate for concrete in buildings, bridges, highway, and dams; for mortar and plaster ; and for asphalt paving and road fill. Sand is also used for special industrial purposes such as blast sand, engine sand, filtration sand, hydrafrac sand, molding sand, as metallurgical flux and as glass sand. Specifications are different for each purpose and for certain special purpose sands, specifications are extremely exact. For example, glass sand must be medium fine-grained quartz sand containing at least 95 percent silica (SiO_2) and less than 0.05 percent iron oxide (Fe_2O_3) ; more iron would impart a color to the glass.

Hydrafrac sands, consisting of well-rounded quartz grains of uniform size, are used for maintaining or increasing the porosity, and consequently, the production of oil wells. Such sands are pumped under pressure down the well and forced into cracks in the oil-producing zone, generally after it has been broken and fractured by an explosive charge. The sand keeps the fractures open and yet is porous enough to permit oil to flow into the well bore.

Blasting sand is usually composed of angular, fine-grained quartz fragments. Sand, sandstones, and quartzite used as metallurgical flux must be clean, for impurities might upset the metallurgical process and harm the final product, whether it be steel or elemental phosphorous. Other clean quartz sands, sandstones, and quartzites are used in the production of ferrosilicon alloys and silicones, a group of silica-based plastics that are being put to ever-increasing uses. For more details on specifications reference should be made to publications of the American Society for Testing Materials and U.S. Bureau of Mines Bulletin 585, Mineral Facts and Problems.

PAST PRODUCTION

Sand and gravel production in New Mexico has been recorded since 1906, and expect for a 7-year gap between 1913 and 1919 is essentially complete. From 1906 to 1933 a total of 5,814,258 shore tons, valued at $3,683,646, was produced (Talmage and Wootton, 1937, p. 150). Between 1934 and 1963 a total of 104,034,132 short tons valued at

$104,041,357 has been produced (U.S. Bureau of Mines Yearbooks, 1934 to 1963) giving the State a total known production of 109,848,390 short tons valued at $107.724.003 for the nresent century (table 451.

TABLE 45.—*Sand and gravel production in New Mexico, 1906–63*

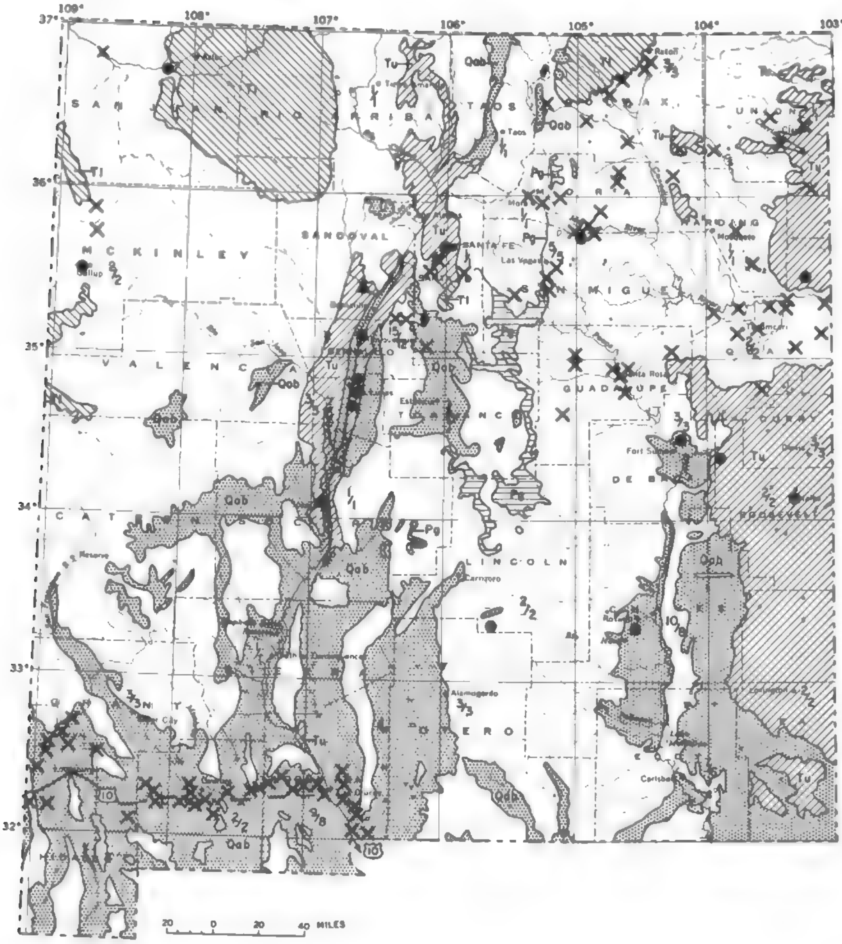
Year	Short tons	Value	Year	Short tons	Value
1906–33 [1]	5,814,258	$3,683,646	1950	937,653	$923,270
1934	161,325	190,879	1951	1,080,256	1,087,857
1935	156,081	104,113	1952	496,921	499,589
1936	2,062,411	1,575,797	1953	1,416,380	1,238,979
1937	1,686,727	974,763	1954	6,519,339	8,340,251
1938 [2]	?	?	1955	4,556,447	6,004,554
1939	1,832,733	1,131,804	1956	6,054,000	5,776,000
1940	2,364,939	1,441,380	1957	7,991,000	7,803,000
1941	1,948,587	1,269,813	1958	13,205,000	11,413,000
1942	261,358	146,866	1959	12,460,000	13,332,000
1943	230,458	147,624	1960	7,419,000	7,459,000
1944	439,286	292,601	1961	12,523,000	10,049,000
1945	448,438	317,968	1962	6,889,000	8,021,000
1946	349,688	278,442	1963	8,403,000	12,844,000
1947	540,794	492,583			
1948	717,088	573,385	Total	109,848,390	107,724,000
1949	883,223	610,839			

[1] Sources: Talmage and Wootton, 1937, p. 150, and U.S. Bureau of Mines Minerals Yearbooks, 1934 through 1963.
[2] Data obscure. Listed with miscellaneous.

Recent production includes pit-run and screened sand and gravel and crushed gravel for aggregate and ballast. Industrial sand for special purposes has been limited to the production of small tonnages of engine sand, roofing sand, and abrasives, according to U.S. Bureau of Mines production records.

DISTRIBUTION OF DEPOSITS

Figure 64 shows the location and distribution of sand, gravel, and sandstone deposits that have been mined or prospected and recorded on published maps. These data were compiled mainly from Talmage and Wootton (1937), the Arkansas River Basin Study of 1943 in the Canadian River drainage, and from the 1958 edition of the New Mexico Non-Metals Resource Map (scale 1: 600,000) for the rest of the State, except for the southwest corner which is from a State Highway report on roadbuilding materials for Interstate Highway 10. Unfortunately much of these data are incomplete or out of date due to the transitory nature of operations which employ portable mining and plant equipment. Recent annual reports of the Federal and New Mexico Bureaus of Mines show that nearly every county in the State has produced sand and gravel at one time or another. Annual reports of the State Inspector of Mines of New Mexico list the pits or quarries and operating companies by name in each county. Although no maps or details of location are given it is reasonable to assume that most are near major centers of population within their respective counties. A comprehensive report by Lovelace and others (1962) shows sand, gravel, and other resources needed in the construction of Interstate Highway 10 through Hidalgo, Luna, and Dona Ana Counties. Detailed location maps and sample reports give precise locations of the deposits and quality of the material for highway construction purposes along Interstate Highway 10. Similar reports of this type would be useful in other parts of the State, especially where new, large



EXPLANATION

Qab

Quaternary alluvium, bolson deposits, dune sand; includes Gila Conglomerate in southwestern part of State

Tu

Middle and Late Tertiary deposits; includes Ogallala Formation in eastern part of State and Santa Fe Formation in north-central part

Tl

Early Tertiary deposits, includes San Jose, Chuska, and Ojo Alamo Formations in western part of State; Raton and Galisteo Formations in eastern part

Pg

Permian Glorieta Formation in central part of State has been suggested as source of silica sand

● Active or recently active operation

× Reported occurrences (operating status not certain)

♦ Reported silica sand deposit

▲ Roofing sand deposit

3/3 Sand and gravel operations/number of operators in 1961, by counties

FIGURE 64.—Sand and gravel in New Mexico.

construction projects are contemplated. However, because of the general lack of information on location of current operations throughout much of the State, sand and gravel mining activity for 1962 [1] is represented on the map by fractions in each county; the numerator represents the total number of pits or quarries in each county and the denominator represents the number of companies that were in operation at that time. These readily show that major activity is concentrated near the major centers of population and industrial expansion. Albuquerque in Bernalillo County has consistently led the State for a number of years with the Springer Transfer Co. and Albuquerque Gravel Co. being the largest operators (Elston, 1961, p. 163). In 1962, this city was followed by Roswell in Chaves County, Las Cruces in Dona Ana County, Farmington in San Juan County, Raton in Colfax County, and Carlsbad and Artesia in Eddy County.

Sand and gravel deposits of New Mexico are so widespread and abundant that much of the accompanying map would be covered if all geologic units that contain potential sources of sand and gravel were shown. Therefore, only the largest, most continuous deposits are included to demonstrate their distribution. Principal deposits consist of alluvial sand and gravel of Pleistocene to Recent age that comprise the bed of the Rio Grande and adjacent terraces and plains. They extend from north of Bernalillo in Sandoval County southward to the Texas and Mexico borders. Such deposits are particularly widespread in Dona Ana, Luna, and Sierra Counties. Similar large deposits are found on the Rio Grande in Taos County to the north and on the drainage of the Pecos River in Chaves, Eddy, and Lea Counties to the southeast. Smaller deposits of the same type and pocketlike lenses filling old channels, known as bolson deposits, are found in the upper reaches of the Pecos River, along the Canadian River, and their tributaries in the northeastern part of the State. Some of these are undoubtedly derived from sandstones and conglomerates of the Ogallala formation which crops out mainly along the eastern boundary of the State and of the Santa Fe Group in the north-central part. One of the more well-known sand and gravel pits in the Ogallala Formation is that operated by Sam Sanders, 6 miles south of Portales in Roosevelt County, where a large variety of Tertiary fossil animal remains have been discovered (Hahn, 1963, p. 747). Similar deposits are also associated with older Tertiary (Paleocene, Eocene, and Oligocene) and Cretaceous formations that include the Wasatch, Torrejon, and Puerco Formations and the Ojo Alamo Sandstone in the western part and the Raton and Galisteo Formations in the eastern part of the State. Only the largest areas of these formations are indicated on figure 64 and appear to be of primary importance mainly in San Juan County and especially near Farmington and Aztec.

Numerous State and Federal geologic reports and water supply papers describe local sand and gravel deposits and many are shown on the maps which accompany them. Elston (1961, p. 1963) states that "all of the sand and gravel in Bernalillo County comes from Quaternary terraces of the Rio Grande, especially the lowest terrace above the present flood plain."

Smith and others (1961, p. 41) mention large acreages of terrace gravels that were mined to provide fill and aggregate for the Abiquiu

Data compiled from 50th Annual Report of the State Inspector of Mines, June 30, 1962.

dam, and for the earth-fill structure in Chama Canyon, Rio Arriba County. Tonking (1957, p. 35) describes extensive deposits of pediment-capping gravels in T. 1 and 2 N., R. 6 W., in the Puertecito quadrangle, Socorro County. Both terrace and pediment gravels are extensive in canyons east of the Mimbres River Valley in Grant, Luna, and Sierra Counties (Elston, 1957, p. 13). Jicha (1954, p. 30-31) describes Pleistocene(?) gravels and younger terrace gravels as well as bolson deposits and alluvium in the Lake Valley quadrangle, Grant, Luna, and Sierra Counties.

The production of sand for special purposes has been very limited. Wind-blown dune sands have been used by the Marvel Roofing Co. of Albuquerque for roofing sand from deposits along the Jemez River near Santa Ana Pueblo in Sandoval County (Elston, 1961, p. 1964). Elston also states that the Glorieta Sandstone of Permian age has been explored at the eastern end of the San Pedro Mountains, Santa Fe County, by the New Mexico Quartz Manufacturing Co., Inc. There the Glorieta is a nearly pure, poorly cemented quartz sand that may be suitable for glass manufacture or other industrial purposes. Elsewhere it is cemented by calcium carbonate or iron oxide. The distribution and characteristics of the Glorieta are described by Needham and Bates (1943) and Baars (1961).

The Zuni Sandstone, mentioned as a possible source of industrial sand, is a white sandstone. It is considered to be equivalent to parts of the Entrada, Todilto, Summerville, Bluff, and Morrison beds (Smith, 1961, p. 125). The Chuska Sandstone, consisting of pale gray to pale yellow, cross-bedded, massive sandstone 1,000 feet thick, has been mentioned as a possible source of glass sand by Allen (1955).

RESOURCES AND Fu'ruRE

Sand and gravel production, similarly to construction, is usually closely related to the growth of population in the United States. Figure 65, however, shows that New Mexico has increased from 61,547 people in 1850, when the first census was taken to 951,023 in 1960. Except for a slight decline (—1.8 percent) during and shortly after the Civil War the population has steadily grown although the rate of growth has fluctuated sharply. Since 1940 it has increased steadily at a rate of about 2.8 percent annually. During approximately the same period, however, sand and gravel production increased erratically, especially after 1952 (fig. 66), undoubtedly reflecting periodic demands mainly for highway construction.

In 1960 New Mexico ranked 37th in population among the States closely matching its rank (35th) in sand and gravel production. Using production figures of 1960 as a base one may estimate that the average annual production is about 7.8 tons per person or approximately twice the national average for the year. Estimates of future consumption indicate that by the year 2000 the national average consumption may be 17 tons per person, or 4.25 times that of 1960 (H. Kirkemo, 1963, personal communication). Assuming an average population increase in New Mexico equal to that of the Nation as a whole it is reasonable to predict that annual sand and gravel production of the State will be approximately 4 times present usage or on the order of 32 million tons per year by the year 2000. If, on the other hand, New Mexico continues to populate at its present rate of 2.8 percent per year and

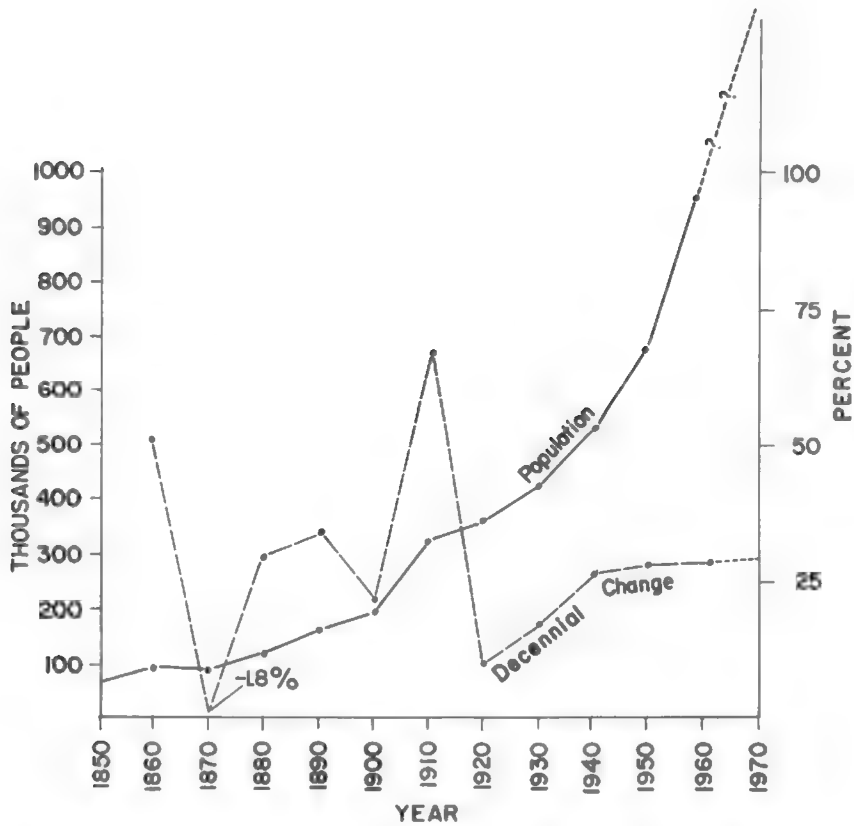


FIGURE 65.—Population growth in New Mexico, 1850 to 1960, according to the U.S. Bureau of Census, with percentage of decennial change.

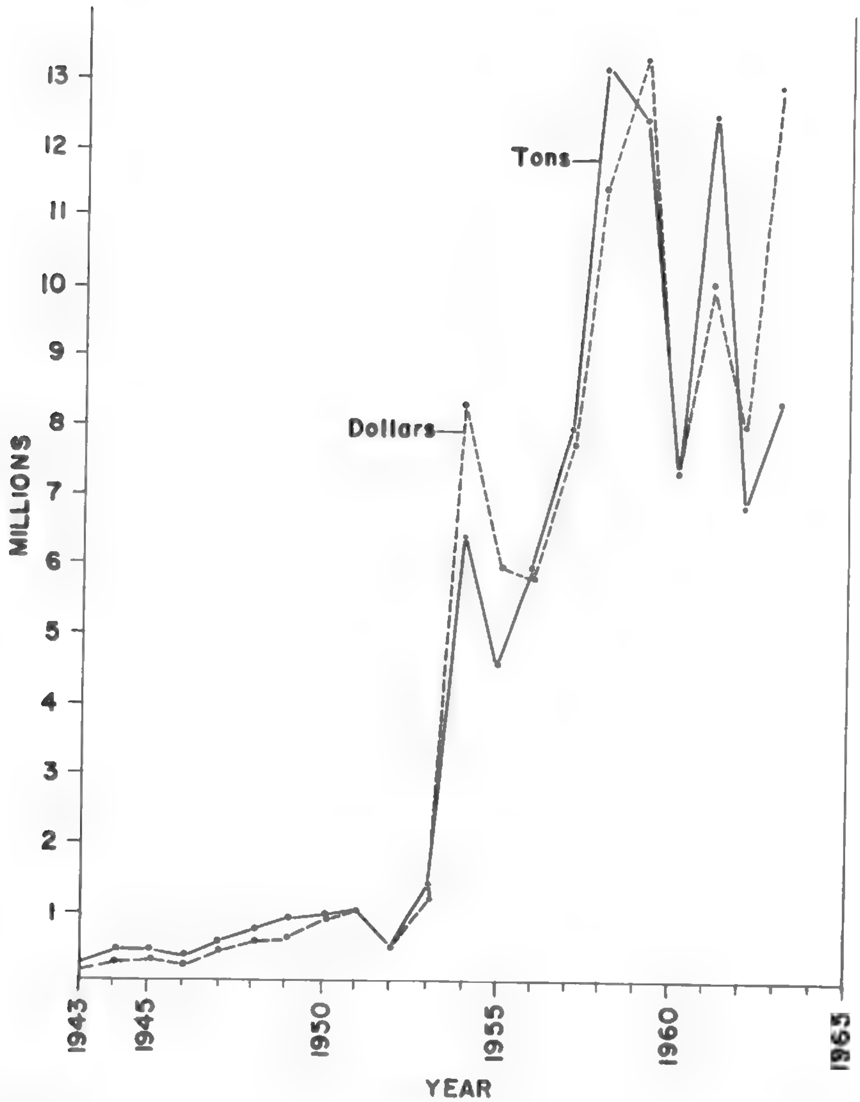


FIGURE 66.—Sand and gravel production and its total value in New Mexico, 1943–1963.

consume sand and gravel at twice the national average, the demand could be considerably greater.

Although New Mexico ranks 37th in population among the States, it is fifth in the amount of land area that it contains (121,511 square miles). Nearly half of the State is covered by materials that could be or are currently being utilized for sand and gravel (Talmage and Wootton, 1937, pp. 40-41) .

There is no single known published report which assesses the quantity and appraises the quality of New Mexico's sand, gravel, sandstone, conglomerate and quartzite deposits for such special purposes as glass sand, molding sand, filter sand, abrasives and blasting sand, hydrafrac sand or as metallurgical flux. A few isolated reports contain data on materials for special purposes. Allen and Balk (1954, p. 19), for example, analyzed sand from the Fort Defiance and Tohatchi quadrangles hoping to find material of sufficient quality to make green glass and, thereby, create a new Indian handicraft industry. Allen (1955) found that although most of the sand is rich in iron a light green glass, pleasing to the eye, could be manufactured. His map also shows the location of many other usable raw materials; it is a type of initial study that could be extremely useful to the State in the future. More work of this type is recommended.

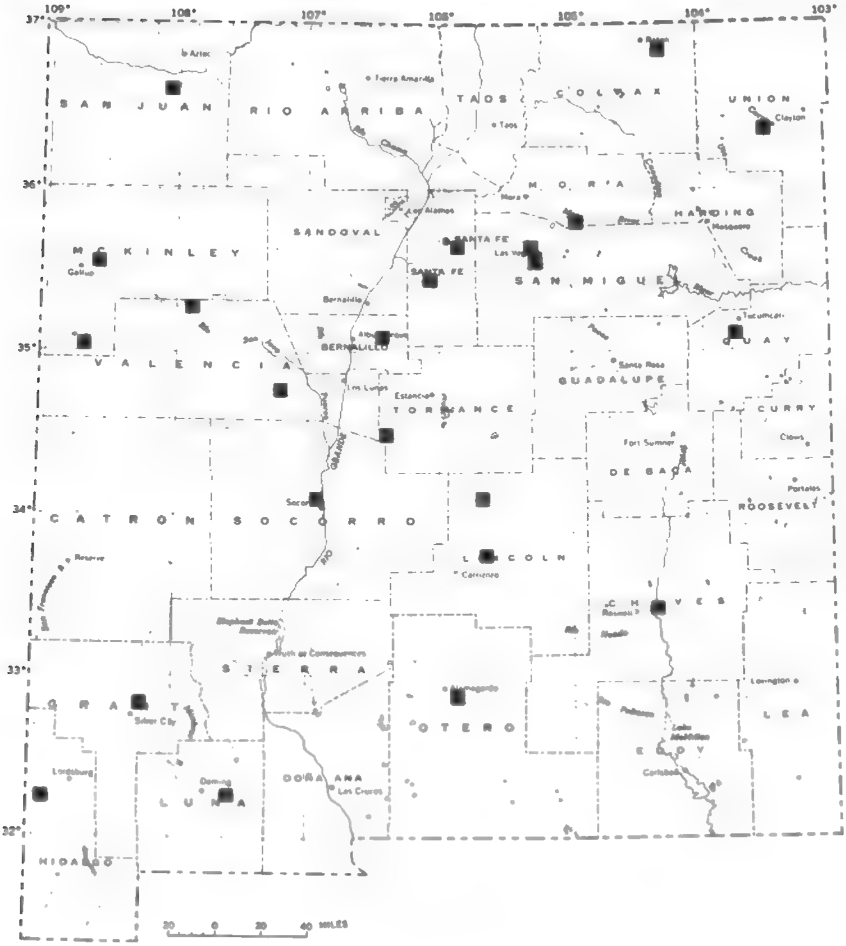
If 46 percent, or 55,895 square miles of the surface of the State contains material that is suitable for construction purposes, New Mexico has no problem as far as sand and gravel resources for the future are concerned except possibly in certain local areas. Efforts should be made, however, to determine what new uses these supplies might best serve. Such studies would serve three important purposes : (1) insure that the raw materials are being utilized in the best manner possible; (2) encourage established enterprisers in the State to expand into new fields, thereby making other industrial materials more readily available; and (3) possibly encourage new industries into the State.

STONE

(By R. M. Lindvall, U.S. Geological Survey, Denver, Colo.)

Stone, because of its widespread occurrence, attractive appearance, strength, and durability, has been used by man as a building material since the dawn of civilization. In New Mexico, however, the availability of adobe has discouraged the opening of stone quarries on a large scale, although many communities have utilized small quantities of local stone for various purposes. Moreover, in modern construction, concrete, brick, steel, and glass are used extensively, and stone is employed only where it is the most economical material available, or where decorative effects make it especially desirable for a particular project. In recent times, however, the increased demand for crushed stone as aggregate in concrete and asphalt road construction and as raw material in the chemical industries has improved the economic position of stone. In 1963 the value of stone production in New Mexico increased 52 percent over 1962.

Most parts of New Mexico contain deposits of stone that are within short haulage distances of population centers. Every county in the State contains potentially marketable stone, but most of these deposits have not been studied or evaluated. Areas in which records indicate that stone has been quarried are shown in figure 67.



EXPLANATION

Areas in which stone quarries are recorded

FIGURE 67.—Stone in New Mexico.

The stone industry is generally divided into two main branches, crushed and broken stone, and dimension stone. In New Mexico in 1963 the production of crushed and broken stone valued at approximately $4,225,000 far exceeded the production of dimension stone which was valued at about $2,600.

Crushed stone is used as aggregate in concrete construction, for road metal and as aggregate in asphalt road construction, as railroad ballast, riprap, in filter beds, roofing granules, in terrazzo, and as decorative material in gardens, patios, and other types of landscaping. Broken stone has become popular for use in rubble walls, fireplaces, patio floors, and as steppingstones, especially in homes and other small structures where decorative accents and special architectural effects are desired. In addition, large quantities of crushed and broken stone are used in the production of lime and cement, in sugar refining, and in metallurgical processes. Stone for these uses is discussed elsewhere in this report.

Crushed and broken stone are obtained from a variety of igneous and sedimentary rocks in New Mexico, but the largest volume is produced from basalt and limestone. Desirable qualities for use as crushed and broken stone include strength, durability, and ease of quarrying and processing. The rock should crush to firm, roughly equidimensional granules, with minimum amounts of dust and powder. Bonding quality is important in rock to be used as aggregate. Limestone ordinarily makes ideal concrete aggregate, and basalt and limestone generally adhere to bitumen better than granite or sandstone, although any of these rocks may serve as aggregate. Rock which is to be used as railroad ballast should be hard, durable, and crush to sharp-edged particles. Stone to be used for decorative purposes is selected chiefly on the basis of attractive appearance, but strength and durability are also important.

Crushed stone for highway construction is generally produced by portable equipment in roadside quarries that are only in operation long enought to satisfy the immediate demand. Large quantities of crushed sandstone have been used for road aggregate in New Mexico in past years, but in 1962 basalt and related rocks (traprock) supplanted sandstone almost completely. Consumers have developed a variety of specifications for crushed stone and reference is made to reports of the following groups : U.S. Department of Commerce, (Bureau of Public Roads), American Roadbuilders Association, the American Association of State Highway Officials, American Society for Testing Materials, and the National Crushed Stone Association.

Dimension stone consists of blocks, slabs, or sheets of stone which are either sawed or chipped to specific dimensions for structural, ornamental, or monumental uses. In the past, dimension stone was used extensively as building blocks to support the full weight of the structure. More recently, however, supporting structures have been mainly of steel or reinforced concrete, and stone is used chiefly as a decorative veneer. Some dimension stone is used in constructing ashlar masonry walls, and also for decorative purposes as ornamental stone, including panels for interior and exterior walls, window sills, mantels, and tops for furniture and lavatories. There is also a continuing demand for dimension stone for use as monuments in cemeteries. As noted previously the 1963 production figures for dimension stone in New Mexico were relatively modest, but a new $100,000

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plant to produce travertine, or onyx marble, was opened in Valencia County in 1963, and efforts were made to reopen a quarry and plant in San Miguel County in 1962 which was to produce monumental granite.

Dimension stone can be developed from a variety of rock types including sandstone, limestone, marble, travertine, quartzite, granite, basalt, and related igneous rocks. The type of rock is commonly not as important as is the color, durability, texture, and freedom from flaws. Deposits of rock should be large enough to develop a sizable quarry, and thickness of overburden should not be excessive.

The United States has sufficient demands reserves of dimension and ornamental stone to meet domestic demands for many years to come, but producers have difficulty in satisfying the public demand for variety. As a consequence special types of stone are imported, chiefly from Europe. If deposits can be found in the State which would supply the demand for rare and unusual types of dimension stone, New Mexico is favorably located with respect to transportation facilities to both the west coast and west Texas consuming centers.

PRODUCTION AND OCCURRENCES

Dollar values of the chief types of stone produced in New Mexico 1958-62, are shown in table 46. Some totals are incomplete owing to figures withheld to prevent disclosure of confidential information.

TABLE 46.—*Stone production in New Mexico, 1958–62*

Year	Granite	Basalt and "traprock"	Marble	Limestone	Sandstone	Other stone
1958	$24,500	$9,000	$2,500	$801,487	$669,790	------
1959	------	5,200	732	296,648	179,996	$57,376
1960	2,492	21,750	------	927,717	1,105	739,312
1961	------	2,025	11,029	1,516,250	87,587	588,775
1962	------	201,758	------	1,298,410	1,125	1,280,947
Total	26,992	239,733	14,261	4,842,512	939,603	2,666,410

As previously noted, most parts of New Mexico contain deposits of marketable stone, and small quantities of stone have been produced from many of these deposits. Areas from which stone is, or has been, produced are shown on figure 67. Quarries from which stone for highway construction has been obtained are for the most part not located on this map, due to the transient nature of most of these operations.

Quarries which are currently in operation (1963) producing dimension stone include the Gallinas mine, northeast of Las Vegas in San Miguel County, where the Alaska International Corp. is producing monumental and ornamental granite. Also near Las Vegas, the Mavalo mine of the Mavalo Stone Co. is producing flagstone. In Valencia County, about 25 miles west of Los Lunas, Ultra Marbles, Inc., has recently opened a quarry for the production of travertine, or onyx marble, to be sold as decorative dimension stone.

Many small quarries were formerly operated in the State. The Almora Marble Co. operation in Marble Canyon about 3 miles east of Alamogordo in Otero County, where a 30-foot-thick bed is exposed, produced marble for a variety of uses. A cream-colored sandstone (Glorieta Sandstone) was quarried near Lamy in Santa Fe County and has been used in the construction of some public buildings in

Santa Fe. Dark-red, gray, and brown sandstones from quarries west of Las Vegas have been used in buildings at New Mexico Highlands University. Other quarries in various parts of the State have produced small quantities of stone for local use.

The future potential of the dimension stone industry in New Mexico is dependent on the creation of new markets and uses for a readily available resource. Deposits of durable and attractive stone are widespread throughout the State. Economic factors rather than rock quality will probably continue to dictate the location of crushed rock operations, with quarries being developed as close to the consuming areas as possible.

Miscellaneous Mineral Resources

ANTIMONY, ARSENIC, BISMUTH, AND CADMIUM

(By M. D. Dasch, U.S. Geological Survey, Washington, D.C.)

Antimony, arsenic, bismuth, and cadmium occur as accessory constituents in many mining districts of New Mexico. Several of these commodities have been recovered as byproducts during the smelting and refining of metallic ores mined in the north-central and southwestern part of the State. Of the four elements, cadmium is the only good conductor of heat and electricity and, therefore, the only true metal. Antimony, arsenic, and bismuth are commonly referred to as semimetals or metalloids, for they have properties that are intermediate between those of metals and nonmetals. The characteristics, uses, and production of each of these four elements are briefly described in the following paragraphs.

ANTIMONY

Antimony is an element that can occur in several different forms, a property referred to as allotrophy. In the common form, it is a brittle, tin-white material with a metallic luster.

Antimony is found in two types of deposits : one type is simple both mineralogically and structurally, the other is complex. The simple type consists predominantly of stibnite (antimony trisulfide), native antimony, and in places their oxidized equivalents. The minerals occur in siliceous gangue and may be accompanied by small quantities of pyrite and other metallic sulfides. In the complex type of deposit, antimony is present in sulfosalts of copper, lead, and silver, or in sulfides of copper, lead, zinc, and silver. Stibnite less commonly is the principal antimony mineral in these complex ore bodies. Antimony ore mined in the United States has come primarily from the complex type of deposits; the New Mexico deposits are of the complex variety.

Antimony generally is a byproduct, at times a coproduct, recovered from metallic ores, especially those of lead. Antimony ores range from low grades of 1 or 2 percent to high grades that approach the limit of pure stibnite, 71.5 percent antimony. The element is alloyed with certain metals to harden them and to inhibit corrosion. In 1962, the most recent year for which complete production statistics are available, the greatest consumption outlet for antimony was as antimonial lead. Significant quantities of the element were used in plastics, flameproofing chemicals and compounds, pigments, and in ceramics and

glass (Spencer and den Hartog, 1963a, table 7) . Although antimony possesses no indispensable properties, it is technologically superior to other elements in many of its uses. Furthermore, it is relatively inexpensive and can be substituted for more expensive metals.

Metallic ores from some mining districts in the State contain antimony-bearing minerals : most commonly, tetrahedrite (copper, iron, antimony sulfide) ; and two silver-antimony sulfides, pyrargyrite, sometimes referred to as "dark ruby-silver", and stephanite. Stibnite occurs locally in several districts.

Antimony production in New Mexico has been negligible. Stibnite has been mined in Grant County (Anderson, 1957, p. 12), and 5 tons of antimony ore were produced in Hidalgo County during 1948.

ARSENIC

Arsenic is a brittle poisonous, allotropic element that is widespread in small quantities. In the common form it has a near-metallic luster and is tin-white or silver gray ; exposure to air turns it black. Arsenic seldom occurs in the native state; instead it is combined with metals such as copper, lead, cobalt, nickel, iron, and silver, with or without sulfur.

Arsenic is recovered as a byproduct during the processing of copper, lead, and less commonly, gold and silver ores. No domestic deposits are mined solely for arsenic content at the present time. Elemental arsenic has not been recovered as a byproduct in this country since 1950. Instead, the element has been produced and consumed as arsenic trioxide or arsenious oxide, commercially called white arsenic. It is used primarily in the manufacture of calcium and lead arsenate insecticides. Since 1944 there has been a marked decrease in its consumption, owing to public preference for less toxic, organic insecticides, such as DDT. The only extensive application of white arsenic, other than as a poison, is in glassmaking.

Metallic ores from some New Mexico mining districts contain a great variety of arsenic-bearing minerals, some of them in appreciable amounts: arsenopyrite (iron arsenide-sulfide) ; proustite (silver arsenic sulfide) , sometimes referred to as "light ruby-silver"; tennantite (copper, iron, arsenic sulfide) ; and scorodite (hydrated arsenate of iron and aluminum). Several rare arsenic minerals, such as endlichite (chloride-arsenate and vanadate of lead), are present in unusual amounts in isolated mines or districts of the State; they will be discussed by district in a later section.

A carload of arsenic ore was shipped from Hidalgo County, N. Mex., in 1924 (Northrop, 1959, p. 86). At the time the commodity commanded a high price owing to serious crop damage in the South by the cotton boll weevil. Arsenious oxide was recovered annually from New Mexico ores during the period 1938-48 ; production figures are not available. There has been no recorded production since 1948 (U.S. Bureau Mines, Minerals Yearbook, annual volumes, 1938-62).

&swum

Bismuth is a brittle, reddish-silver element that has a metallic luster and is chemically similar to antimony and arsenic. It is present in small quantities throughout the world. Native bismuth and a number

of bismuth-bearing minerals generally occur in stringers and pockets in hydrothermal veins. In some places, bismuth enters into the crystal lattice of certain ore minerals such as galena (lead sulfide). Few deposits are sufficiently concentrated to be mined solely for bismuth. Generally it is produced as a byproduct of lead ores, and to a lesser extent of copper, tungsten, and gold ores.

In 1962, 65 percent of the bismuth metal consumed in the United States was used in fusible and other types of alloys. Thirty-four percent was used in pharmaceuticals, and in other industrial and laboratory chemicals (Spencer and den Hartog, 1963b, p. 322). In the future bismuth may become increasingly important in nuclear and electronic applications, and in thermoelectric elements and liquid metal reactors. Although other metals can be substituted for the element in some of its uses, bismuth has a relatively stable position in the present economy.

Ores mined in some New Mexico districts contain significant amounts of several bismuth-bearing minerals: bismuthinite (bismuth trisulfide) ; bismutite (bismuth subcarbonate) ; bismite (bismuth trioxide) ; and two bismuth tellurides, tetradymite, and tellurobismuthite.

In 1908 and 1911 small amounts of bismuth ore were shipped from claims on the east side of the San Andres Mountains in south-central New Mexico. In 1936 the American Bismuth Mines recovered bismuth from ore mined near Tyrone, Grant County. Bismuth was recovered annually from New Mexico ores during the period, 1940-48, but production figures are not available. Production has not been reported since 1948 (U.S. Geological Survey, Mineral Resources of the United States, annual volumes, 1908, 1911; U.S. Bureau Mines, Minerals Yearbook, annual volumes, 1936 48). Choice specimens of New Mexico bismuth minerals have been sold to many museums.

CADMIUM

Cadmium is a soft, ductile, bluish-white metal that is produced commercially from two sources. One is greenockite, a rather rare, yellow to orange cadmium sulfide that commonly occurs as a powdery coating on zinc minerals, especially sphalerite. The other source consists of zinc sulfide, where cadmium is in solid solution with the mineral. It is recovered only as a byproduct. Cadmium is used primarily in electroplating, especially in transportation and communications equipment, and in fasteners. Significant quantities of cadmium are consumed in the production of pigments and chemicals.

Ores mined in the western United States contain varying amounts of cadmium but average about 0.25 percent of the metal. Zinc concentrates produced in New Mexico are shipped outside the State for treatment, and the contained cadmium presumably is recovered during smelting. There is, however, no published record of the amount of cadmium that is recovered, thus there is no way of determining the amount of cadmium produced in the State and consequently no way of estimating the reserves of cadmium in unmined ores.

NEW MEXICO OCCURRENCES

Occurrences of antimony, arsenic, bismuth, and cadmium in the mines and mining districts of New Mexico have been reported in summary and tabular form by Lasky and Wootton (1933). Anderson

(1957), Burnham (1959), Warner and others (1959), and Northrop (1959) . Bismuth occurrences in the State have been annotated by Cooper (1962), and antimony occurrences have been listed by White (1962). Ore deposits containing one or more of these four elements are briefly summarized in the following paragraphs by county and by district; their locations are shown on figure 68.

Catron County :

Mogollon district (fig. 68, No. 27) : Clinoclase, an arsenate of copper, occurs in or near this gold-silver district as nodules and crystals.

Wilcox district (No. 28) : Bismuthinite is mixed with tellurium at a tellurium prospect.

Colfax County :

Baldy district (No. 2) : An appreciable amount of tetradymite, a bismuth telluride, occurs with gold ore.

Raton, New Mexico-Trinidad, Colorado region (No. 1) : In coal mines of the area, black "sulphur balls" up to a foot in diameter are composed of about one-third arsenopyrite.

Dona Ana County :

Gold Camp district (No. 19) : Bismuth minerals occur with gold-copper ore in veins in Precambrian granite.

Organ district (No. 21) : In this copper-lead-zinc-silver district, the antimony mineral, tetrahedrite, is abundant at the Hawkeye group and at the Silver Moon claim near the Silver Coinage mine. Bismutite is common at several mines, and tetradymite is locally abundant at the Memphis mine. Copper ores shipped from the Memphis mine in the early part of the century were reported to average 1 percent bismuth.

Texas district (No. 20) : Ore shipped from the Texas Canyon mine at one time was estimated to average 1 percent bismuth.

Grant County :

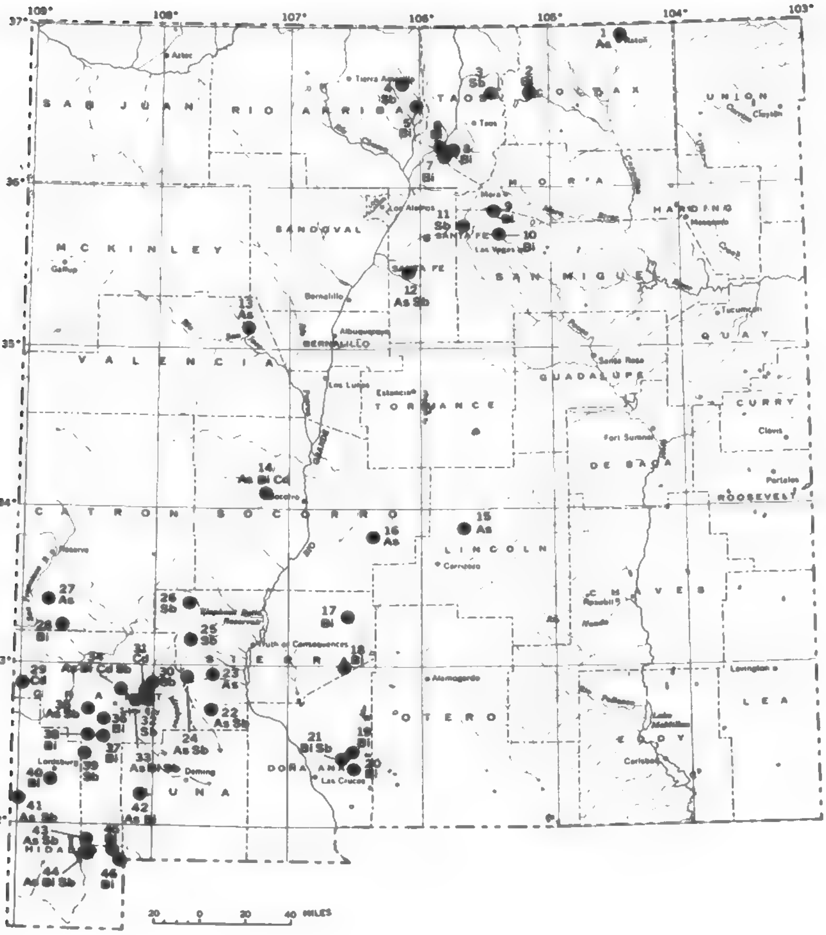
Black Hawk district (No. 35) : Pyrargyrite is one of two silver-antimony sulfides that occur in the Rose mine. A number of arsenic minerals are present in fissure veins in the district; the majority are arsenates and arsenides of cobalt or nickel or both, such as skutterudite, nickel-skutterudite, and annabergite.

Burro Mountains district (No. 36) : Native bismuth and several bismuth minerals occur at the American Bismuth Mines, and masses of tetradymite, up to an inch across, are reported in the Little Burro Mountains. In 1936 bismutite was mined in the district by the American Bismuth Mines.

Central district (No. 33) : Both antimony and arsenic minerals occur in ores of this zinc-copper-lead district. Bismuth is present in calc-silicate ores and vein deposits of the district.

Eureka district (No. 43) : Stibnite has been mined in the district and tetrahedrite is one of the most abundant sulfides at the Silver King mine. Arsenopyrite is common at the American mine and scorodite, a hydrated arsenate, is prominent at the Mispickel tunnel.

Fierro-Hanover district (No. 31) : Oxidized zinc ores mined in the vicinity of Hanover were reported, in 1909, to contain cadmium sufficient enough to impart a strong yellow tint to the zinc oxide produced from them. Minor amounts of cadmium occur in the zinc sulfide concentrates.



EXPLANATION

Mining district or deposit

As Arsenic Cd Cadmium

Bi Bismuth Sb Antimony

FIGURE 68.—Antimony, arsenic, bismuth, and cadmium in New Mexico. (Numbers refer to localities mentioned in text.)

Georgetown district (No. 30) : Pyrargyrite occurs in silver ores of the district.

Gold Hill district (No. 39) : Pyrargyrite has been mined in this gold-silver district.

Malone district (No. 38) : Bismuth is distributed throughout the district. In one area where the element may be of economic importance, sorted ore averages 5 to 10 percent bismuth as the mineral bismutite.

Pinos Altos district (No. 34) : Many different minerals occur in this gold-silver-copper-lead-zinc district ; pyrargyrite is present in many mines and stephanite at the Silver Cell property. The silver arsenic sulfide, proustite, occurs in considerable quantity. Bismuth minerals have been reported from a gold vein, and the cadmium sulfide, grennockite, is mentioned in the literature.

Santa Rita district (No. 32) : Both stibnite and tetrahedrite are present in this copper district. Antimony production plus resources in the Santa Rita-Central area has been estimated between 100 and 1,000 short tons contained antimony.

Steeple Rock district (No. 29) : Trace element analyses of sphalerite show a higher than average cadmium content in the Carlisle mine.

White Signal district (No. 37) : Bismite is present in quartz-pyrite veins of the Merry Widow mine. Gold, bismuth, and uranium are the three principal metals at the Apache Trail mine.

Hidalgo County :

Apache No. 2 district (No. 45) : Oxidized bismuth minerals are associated with tungsten deposits. Bismuth has been recovered from ores of the district.

Fremont district (No. 46) : Lead, silver, and bismuth are the principal metals at the Eagle mine. They occur in replacement bodies and quartz-carbonate sulfide veins in limestone.

Lordsburg district (No. 40) : Bismuth is associated with ore minerals in quartz-sulfide veins of this copper-lead-silver district.

San Simon district (No. 41) : A small deposit of stibnite and antimony oxide occurs in a quartz vein in or slightly east of this district. Approximately 5 tons of ore averaging 6 percent antimony was mined in 1948. Arsenic is present in ores of the district but the mineral combination is not known.

Sylvanite district (No. 44) : Stibnite occurs in this copper-gold-silver district and a variety of arsenic minerals has been reported. A carload of arsenic ore was shipped from the district in 1924. Veins with small pockets of bismutite and seams and blebs of tellurobismuthite in quartz occur locally.

Lincoln County : Jicarilla district (No. 15) : Arsenic is present in copper-silver ores but the mineral combination is not known.

Luna County : Vittorio district (No. 24) : Arsenic is present in the lead-silver ores of the district and bismuth has been reported in tungsten and beryllium deposits.

Mora County : Rociada district (No. 9) : Native bismuth and bismutite occur in parts of the Rociada lepidolite deposit.

Rio Arriba County :

Bromide No. 2 district (No. 4) : Stephanite, tetrahedrite, and its silver-bearing variety, freibergite, have been reported from this copper-gold district.

Petaca district (No. 5) : Widespread bismutite occurs as prismatic masses at the Sandoval and Fridlund deposits and as tabular masses at the Globe mine. About 100 pounds of the mineral was produced from the Sandoval deposit in 1943. Native bismuth and bismuthinite also occur in the district but are rare.

San Miguel County :

El Porvenir district (No. 10) : Bismuthinite occurs with molybdenum and tungsten minerals in a pegmatitic gangue on the Bert Hoover Mining Lode No. 1.

Willow Creek district (No. 11) : Tetrahedrite occurs in this lead-zinc district.

Santa Fe County : Cerrillos district (No. 12) : Stibnite, tetrahedrite, and other antimony-bearing minerals are present in this silver-lead-zinc district.

Sierra County :

Chloride district (No. 26) : Tetrahedrite, has been mined.

Grandview Canyon district (No. 18) : Bismuthinite, native bismuth, and bismutite occur in the Pioneer mine and in other workings of the district. The bismuth minerals are associated with scheelite and occur in quartz lenses along a Precambrian schist-granite contact. Minor amounts of ore were produced in 1908 and 1911.

Hermosa district (No. 25) : Tetrahedrite has been mined in this silver-copper-lead district.

Hillsboro district (No. 23) : Endlichite, a chloride-arsenate and vanadate of lead, occurs in replacement deposits in limestone.

Kingston district (No. 24) : Tetrahedrite has been mined. In the late 1800's, beautiful specimens of "Ruby-silver", arsenic-bearing proustite and antimony-bearing pyrargyrite, were recovered from the Kingston mine.

Lake Valley district (No. 22) : Pyrargyrite has been mined in this silver-manganese district. Endlichite occurs as flat crusts and crystals; the district is its type locality.

Salinas Peak district (No. 17) : Both bismutite and bismuthinite are present in copper-lead ores.

Socorro County :

Hansonburg district (No. 16) : Tennantite, a copper iron arsenic sulfide, constituted about 95 percent of the ore minerals.

Magdalena district (No. 14) : Arsenical sulfides occur near Water Canyon. Bismuth has been recorded in analyses of sphalerite and chalcopyrite. Greenockite coats sphalerite and smithsonite, fills cracks and cavities in sphalerite, and occurs as yellow stains within smithsonite.

Taos County :

Glenwoody district (No. 6) : Secondary bismuth minerals occur along quartz veins about 2 miles southwest of Pilar. A small quantity of bismuth ore was produced about 1950.

Harding Mine district (No. 7) : Native bismuth and several bismuth minerals occur with beryllium and lithium ores in pegmatite dikes.

Picuris district (No. 8) : Bismuth is the principal metal at the Goats Point prospect. It occurs in gossan on Precambrian granite.

Twining district (No. 3) : Stibnite occurs in small veins near monzonite porphyry dikes.

Valencia County : Laguna district (No. 13) : Novacekite, a hydrated arsenate of magnesium and uranium, is present in the Woodrow area where it coats a friable sandstone in the Westwater Canyon Sandstone Member of the Morrison Formation. This is the first reported occurrence of the mineral in North America and the second in the world.

Districts discussed in the previous paragraphs are not necessarily the only localities or the most important localities that have ores containing antimony, arsenic, bismuth, and cadmium. Some of the more important deposits may have been disregarded and some of the less important included, owing to a lack of quantitative information.

PRODUCTION AND RESOURCES

The production of these minor elements in New Mexico is, for the most part, dependent upon the mining, smelting, and refining of ore mined for the major metals. Consequently, the recovery of these smelter byproducts is relatively inflexible and a scarcity may arise when the demand is great. Antimony and arsenic are present in lead, silver, and copper ore, bismuth is associated primarily with lead ores, and cadmium is present in zinc ores. Bismuth and arsenic are present in significant quantity locally in New Mexico metallic ores; antimony and cadmium occur in lesser amounts. Whether these products are wasted or conserved when the ores are processed is not known. Production figures are not available from the processing smelters.

On his metallogenic map, White (1962) has shown six New Mexico mining districts which individually have less than 100 short tons of contained antimony (production plus resources) and one district with between 100 and 1,000 short tons of contained antimony (production plus resources) . Resource figures, even approximate ones such as these, are not available for arsenic, bismuth, and cadmium. Nevertheless, as long as New Mexico metallic ores are mined and treated these minor elements will be available for recovery in varying amounts.

NITRATES AND GUANO

(By P. T. Hayes, U.S. Geological Survey, Denver, Colo.)

The nitrate minerals and guano are discussed together because of their common close relationship in nature and because their principal use is as nitrogenous fertilizer. The nitrate minerals of importance are niter or saltpeter (KNO_3) and soda niter ($NaNO_3$) . In addition to use as a fertilizer, soda niter is used in the manufacture of chemicals and gunpowder. Prior to the discovery of large reserves of potassium chloride and sulfate in Permian beds of southeastern New Mexico, there was an interest in saltpeter in the United States as a possible source of potassium.

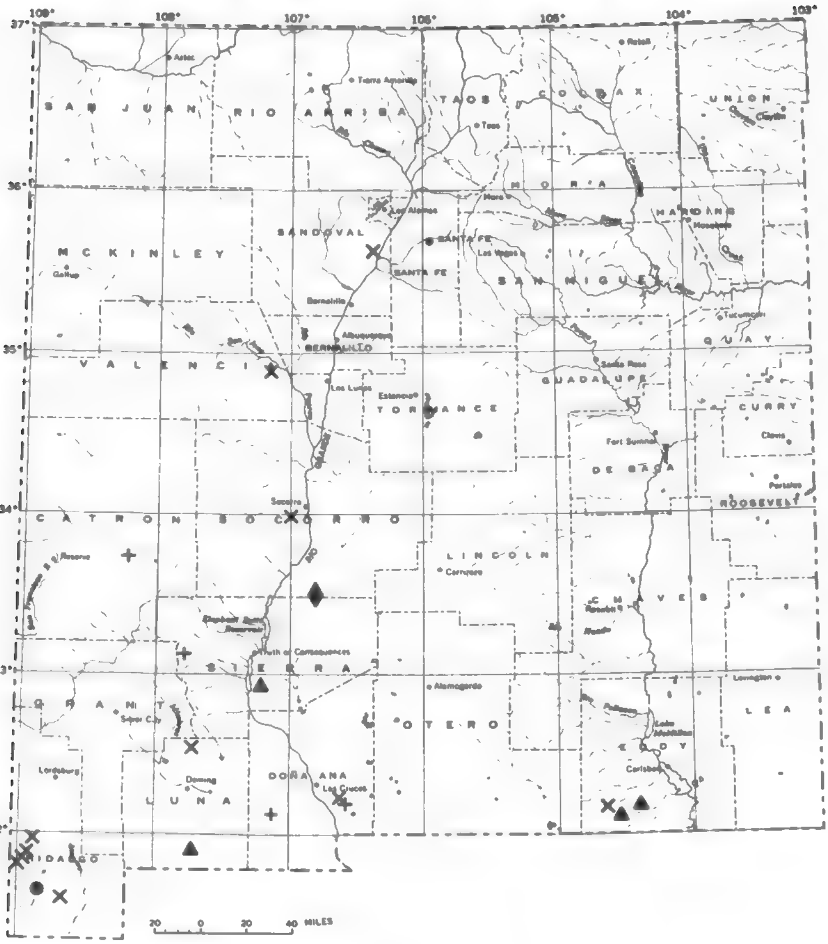
Guano is a natural accumulation of manure, usually mixed with variable amounts of animal remains and inorganic matter. Marine-

bird guano makes up the largest deposits in the world, but bat guano forms smaller deposits in caves throughout much of the world. Nitrate salts occur as surficial percipitates derived from waters that have percolated over or through guano deposits or organic-rich soils. Because niter and soda niter are very soluble in water, they can occur naturally only in very arid regions.

The only large deposits of nitrate minerals in the world are in the extremely arid deserts of northern Chile ; these deposits for many years were the source of most of the world's commercial nitrate. Since about 1900, nitrogen released through the destructive distillation of coal to form coke, and, since 1921, nitrogen fixed from the atmosphere, have become increasingly important sources of nitrogen and nitrogen compounds (Graham, 1949). Fertilizers manufactured as byproducts of modern sewage disposal plants are becoming increasingly important and no doubt have some effect on the demand for guano.

In New Mexico small accumulations of nitrate salts have been found at many localities, mostly in the southern part of the State (fig. 69). Descriptions of most of the known New Mexico occurrences were summarized by Mansfield and Boardman (1932) . Other possible occurrences have been mentioned by Gale (1912), Noble (1931), and Northrop (1959) . Soda niter from the extreme southern edge of New Mexico adjacent to the Mexican border apparently was once mined in small quantities by Mexicans (Williams, 1883), and according to Mansfield and Boardman (1932) about 125 tons of niter was reported to have been mined between 1899 and 1902 from a small deposit in a lava tunnel in Socorro County east of the Rio Grande (fig. 69) . Talmage and Wootton (1937) expressed the opinion that no reported nitrate occurrence in the State offered commercial promise ; there is no reason at present to contradict that opinion.

Bat guano is present in numerous caves in the State but most of the deposits are too small to be of commercial consequence for other than limited local markets. Bailey (1925) estimated that 100,000 tons of guano was removed from Carlsbad Cavern and that the remaining guano "would make but a few carloads." More recently, commercial guano was taken from New Cave, now a part of Carlsbad Caverns National Park. Other areas from which some guano has been mined include a cave in the Caballo Mountains (Kelley and Silver, 1952), one or two lava tunnels in the Jornada del Muerto (Brady, 1905 ; Mansfield and Boardman, 1932), and places in the Tres Hermanas Mountains (Talmage and Wootton, 1937) . The approximate locations of caves from which guano has been mined or is reported to be present in significant quantities are shown on figure 69.



EXPLANATION

×
Nitrate occurrence

+
Guano occurrence

●
Deposit of nitrate that has been mined

▲
Deposit of guano that has been mined

◆
Area where both nitrate and guano have been mined.

FIGURE 69.—Nitrates and guano in New Mexico.

RHENIUM

(By **R.** U. King, U.S. Geological Survey, Denver, Colo.)

Rhenium, one of the scarcest metallic elements, has been intensively investigated since its discovery in 1925. Rhenium metal is silvery white, with a melting point of 3,180° C., the second highest of all metals, and a density of 21 gm/cc, the fourth highest of metals. It is ductile, extremely hard, and has a high tensile strength. Although current production is small, and domestic consumption amounts to less than 1,000 pounds per year, considerable interest exists in this metal for its potential applications in science and industry. In powder form, rhenium sells for S680 a pound and in metallic forms for as much as $1,000 a pound. Rhenium is used today in thermocouples, in filaments for mass spectrographs, and ion gages. Potential uses for rhenium metal and rhenium alloys include electrical contacts, lamp filaments, metallic coatings, heat-, wear-, and corrosion-resistant alloys, and catalysts. Except for the one rare mineral dzhezkazganite, a rhenium-copper sulfide discovered recently in copper ores in Russia, rhenium minerals are not known. Molybdenite in general contains more rhenium than any other mineral. Rhenium is found in molybdenite in amounts ranging from traces to a few tenths of 1 percent, but rhenium has been found in trace amounts in copper, iron, silver, and several other sulfides as well as in wulfenite, powellite, uraninite, and in complex columbium, niobium, and tantalum oxides.

The rhenium content of molybdenite in porphyry copper deposits ranges from a few times to as much as 100 times the content in molybdenite from other types of deposits. Small amounts, ranging from a few parts per million to over 100 parts per million of rhenium, have been found in bedded molybdenum-uranium deposits in sedimentary rocks. Current production of rhenium is derived from the roasting of byproduct molybdenite concentrates which are obtained from the mining of copper sulfide ores in Arizona and Nevada.

Mineral deposits containing economically significant quantities of rhenium are not known to exist in New Mexico, although potential sources might exist in some of the molybdenum deposits of the State (see molybdenum chapter) .

ZIRCONIUM

(By E. C. Bingler, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mex.)

Zirconium is utilized by industry in metallic form and as the natural silicate, zircon. The bulk of zirconium metal is used as an alloying agent in the production of nonferrous alloys with great creep resistance and thermal conductivity. Zircon is employed in the manufacture of foundry molds and as a refractory material. Domestic production of zircon and subsequently zirconium has come largely from secondary deposits in Florida.

Zirconium occurs in nature in the minerals zircon ($ZrSiO4$) and baddeleyite ($Zr0_2$), the latter being a relatively rare mineral. Zircon is a common accessory mineral in igneous, metamorphic, and elastic sedimentary rocks. Its hardness, high specific gravity, and durability

account for the tendency of this mineral to accumulate in residual deposits. Commercial deposits of zircon are found in ancient and recent beach placers.

The only known deposits of possible economic importance in New Mexico are in the Upper Cretaceous titaniferous heavy mineral deposits in the San Juan Basin (discussed in the titanium chapter of this report). The heavy mineral fraction of these deposits averages about 15 percent zircon (Chenoweth, 1957; Bingler, 1963) ; consequently, though the heavy mineral accumulations are extensive, the total amount of zircon present is very small. Preliminary investigation of some of the heavy mineral deposits indicates that small pockets and stringers of sandstone with higher than average zircon concentrations do exist; however, insufficient information is available for a realistic appraisal of their extent. Zircon in these deposits consists of colored and uncolored, fluorescent, rare-earth-bearing varieties. The radioactive nature of the minerals associated with the zircon deposits led to the discovery of the deposits by airborne and field radiometric surveys.

Known sedimentary deposits of zircon are generally far removed from the facilities necessary for easy mining; other, larger deposits are not likely to be found in New Mexico.

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WATER RESOURCES

(By S. W. West, R. L. Cushman, and J. M. Stow, U.S. Geological Survey, Albuquerque, and W. L. Heckler, U.S. Geological Survey, Santa Fe, N. Mex.)

INTRODUCTION

THE HYDROLOGIC ENVIRONMENT

New Mexico is a land of contrasts, physically and socially. It includes portions of the Interior Plains, the Southwestern Desert, the Colorado Plateaus, and the Rocky Mountains. Its inhabitants have a varied background : native Indians, descendants of Spanish colonists, immigrants from foreign lands, and Americans from every State. The physical environment determines the availability of water; the inhabitants determine its use.

Broad plains, wide valleys and basins, high plateaus, and precipitous mountains form the landscape. The altitude ranges from a little less than 3,000 feet in the southeastern part to more than 13,000 feet in the mountains in the north-central part. The altitude and relief profoundly influence the precipitation, the temperature and evaporation, the vegetation, and the availability of water.

Large perennial streams are few and some that are considered to be perennial have at times been dry. Much more common are sandy washes that infrequently are filled for a short time by storm runoff. The principal streams that drain the broad plains of eastern New Mexico are the Cimarron, Canadian, and Pecos Rivers. The Rio Grande, San Juan, and Gila Rivers drain most of the mountains and high plateaus of central and western New Mexico. Several large basins in the central and southwestern parts have interior drainage.

The mean annual precipitation ranges from 8 inches along the lower San Juan and Rio Grande Valleys to 30 inches in the mountains. Most of the precipitation at lower altitudes falls in summer as rapid downpours during thunderstorms.

Water is lost by evaporation from free water surfaces, moist land, and the vegetative cover with the rate of loss increasing with higher temperatures. The average annual temperature ranges from 60° F. in the valleys of the south to 40° F. in the mountains of the north.

The vegetation in New Mexico is as varied as the precipitation and topography. The natural vegetation can be divided into four broad categories : (1) brush, cactus, and grass at altitudes of less than 5,000 feet, (2) pinon and juniper at altitudes of 6,000 to 8,000 feet, (3) pine, fir, and spruce at altitudes of 8,000 to 12,000 feet, and (4) tundra above 12,000 feet. Phreatophytes, water-loving plants, grow profusely along streamways in many valleys. An additional category of vegetation includes all agricultural crops. All plants transpire water ; the amount depends on the type and population density of the plants, and the amount of water available.

The type and density of vegetation affect the runoff and infiltration of water. Sparse brush and grass at lower altitudes and even pinon-juniper growth at intermediate altitudes do little to slow runoff. Channel erosion in these regions is excessive. The dense growth of plants and accumulations of plant debris on mountain slopes delay runoff and aid infiltration. Little of the mountain soil is barren, so the sediment load of the mountain streams is small and channel erosion is negligible. On the other hand, the dense vegetation on the mountains consumes large quantities of water where it falls.

WATER-RESOURCES INVESTIGATIONS

A hydrologic system is an area in which hydrologic characteristics are closely related and which can be isolated, or nearly so, for consideration of causes and effects pertaining to water. Analysis of hydrologic systems is the logical approach to comprehensive water-resources investigations. In New Mexico, hydrologic systems generally coincide with topographic or surface drainage basins, though in some places water moves underground from one basin to another. Most of the hydrologic systems in New Mexico extend across the State boundaries.

Hydrologic units (subdivisions of the systems) can be defined arbitrarily as small topographic basins tributary to the large basins or other convenient study areas (fig. 70) .

Water resources investigations of hydrologic systems and units may be divided into four broad categories : qualitative, quantitative, monitoring, and research. Each has varying degrees of complexity ; however, the quantitative study is the most complete of the four. An investigation of a hydrologic system may begin as a series of unit studies, which eventually are utilized in a hydrologic system analysis.

FIGURE 70.—Hydrologic systems (basins) and hydrologic units in New Mexico.

EXPLANATION FOR FIGURE 70

ARKANSAS RIVER BASIN

1-1 Canadian River basin above mouth of Cimarron Creek
1-2 Cimarron River basin
1-3 North Canadian River basin
1-4 Mora River basin
1-5 Canadian River basin, Cimarron Creek-Mora River
1-6 Ute Creek basin
1-7 Canadian River basin below Ute Dam
1-8 Canadian River basin, Mora River-Conchas Dam
1-9 Canadian River basin, Conchas Dam-Ute Dam

SOUTHERN HIGH PLAINS

2-1 Frio Draw basin
2-2 Running Water Draw basin
2-3 Northern Lea Plateau
2-4 Southern Lea Plateau

PECOS RIVER BASIN

3-1 Pecos River basin above Gallinas River
3-2 Pecos River basin, Gallinas River-Alamogordo Reservoir
3-3 Vaughn Plains
3-4 Pecos River basin, Alamogordo Reservoir-Arroyo de la Mora
3-5 Pecos River basin, Arroyo de la Mora-Rio Hondo
3-6 Mescalero Pediment
3-7 Rio Hondo basin
3-8 Pecos River basin, Rio Hondo-Lake McMillan
3-9 Pecos River basin, Lake McMillan-State Line
3-10 Querecho Plains-San Simon Swale

CENTRAL CLOSED BASINS

4-1 Estancia basin
4-2 Northern Jornado del Muerto
4-3 Northern Tularosa basin
4-4 Southern Jornado del Muerto
4-5 Southern Tularosa basin
4-6 Salt basin

RIO GRANDE BASIN

5-1 Rio Chama basin
5-2 Rio Grande basin, Colorado line-Espanola
5-3 Rio Puerco basin above Rio San Jose
5-4 Jemez River basin
5-5 Rio Grande basin, Espanola-Bernalillo
5-6 Rio San Jose basin
5-7 Albuquerque area
5-8 Rio Salado basin
5-9 Rio Puerco basin below Rio San Jose
5-10 Rio Grande basin, Isleta-San Acacia
5-11 Rio Grande basin, San Acacia-San Martial
5-12 Rio Grande basin, San Marcial-Elephant Butte dam
5-13 Rio Grande basin, Elephant Butte Dam-Radium Springs
5-14 Rio Grande basin, Radium Springs-El Paso

WESTERN CLOSED BASINS

6-1 North Plains
6-2 San Augustin Plains

SAN JUAN RIVER BASIN

7-1 San Juan River basin
7-2 Chaco River basin

LOWER COLORADO RIVER BASIN

8-1 Puerco River basin
8-2 Zuni River basin
8-3 Carrizo Wash basin
8-4 San Francisco River basin
8-5 Gila River basin
8-6 San Simon Creek basin

SOUTHWESTERN CLOSED BASINS

9-1 Animas basin
9-2 Mimbres River basin
9-3 Playas basin
9-4 San Luis basin
9-5 Hachita basin
9-6 Wamel basin

Qualitative investigation is general in nature and has as its goal the delineation of: (1) location of the water; (2) its source; (3) its direction of movement; and (4) its chemical and physical quality. This type of investigation defines the surface drainage system and indicates the perennial and nonperennial sections of the system, determines the general depth to the main ground-water body, the type of water-bearing rock, the probable source of recharge, the general direction of movement, and major points of discharge. The chemical and physical quality of the water is determined for selected sites. A qualitative water-sources study generally is sufficient for a low intensity of development of water in an area and is of great value to developers. Areas in New Mexico where qualitative ground-water investigations have been made by the U.S. Geological Survey in cooperation with the State Engineer Office, the New Mexico Institute of Mining and Technology, and other Federal agencies are shown in figure 71.

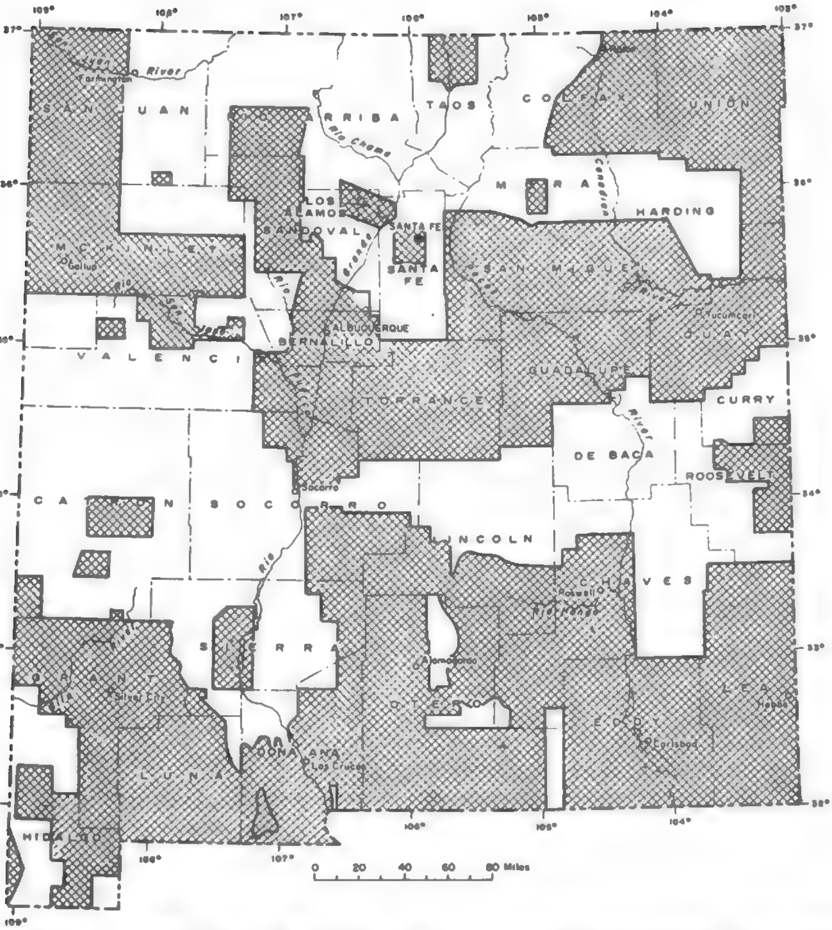


FIGURE 71.—Areas in New Mexico where ground water investigations have been made by the U.S. Geological Survey and the New Mexico Institute of Mining and Technology as of January 1964.

Quantitative water-resource investigation of a hydrologic basin provides these specific values : (1) the spatial extent of the basin; (2) the amount of water in transient storage; (3) the rate of water addition; (4) the rate of water discharge; (5) the rate of sediment and dissolved mineral discharge; (6) the rate and direction of water movement within and through the system; (7) the amount of interference among points of withdrawal; (8) the amount of chemical change within the system ; and (9) data with which to predict the response of the system to manipulation of any of the above factors. Quantitative studies of water resources have been made in only a few small areas of New Mexico.

Collection of selected hydrologic data must be continued, even after a qualitative or quantitative investigation has been completed, to monitor changing conditions. A part of the U.S. Geological Survey program in New Mexico for many years has been monitoring of changes in the hydrologic regimen to permit periodic reevaluation of the hydrologic systems as new and old forces act upon them. The locations of Geological Survey monitoring sites—streamflow gaging stations, quality-of-water collection sites, and areas of water-level observations in wells, are shown in figure 72. (Exact locations of the sites indicated in the figure can be found in U.S. Geological Survey water-supply papers.) Streamflow records are being collected at 193 sites and the stage of reservoirs is monitored at 16 sites. Daily chemical-quality records are collected at 17 of the sites and monthly records at 12. Daily suspended-sediment samples are collected at 21 of the sites and monthly records at 9. The monthly sites are not indicated on the map. Peak floodflow data are being collected at 146 sites; these sites are not indicated on the map. In. 1964 water levels were measured in 1,362 observation wells. Samples of water for chemical analysis are collected from several wells each year.

Hydrologic research provides fundamental knowledge concerning the effect of the physical environment and its changes on the occurrence and quality of water, and develops new methods for hydrologic studies. Part of the research is done in other States and the knowledge gained is applied to solution of water problems in New Mexico ; part is done in New Mexico to solve specific local problems or to sample hydrologic environments common to many regions.

Most of the hydrologic investigations in New Mexico by the U.S. Geological Survey have been made in cooperation with State agencies under the system of cooperative programs. Also, investigations have been made by the Geological Survey using Federal funds allotted directly to the Geological Survey, or in cooperation with other Federal agencies.

WATER PROBLEMS

Many of New Mexico's water problems are caused by uneven distribution and variable quality of the supply. Areas in which water is desired do not always coincide with areas of supply. The largest sources of surface water are in the northern part of the State; the greatest demand for water is in the southern part, where irrigable lands are extensive and the growing season is long. The long surface water transport is conducive to depletion of the water by evaporation and transpiration. The best surface storage sites for water also are in the northern part of the State. In general, the best sites for stor-

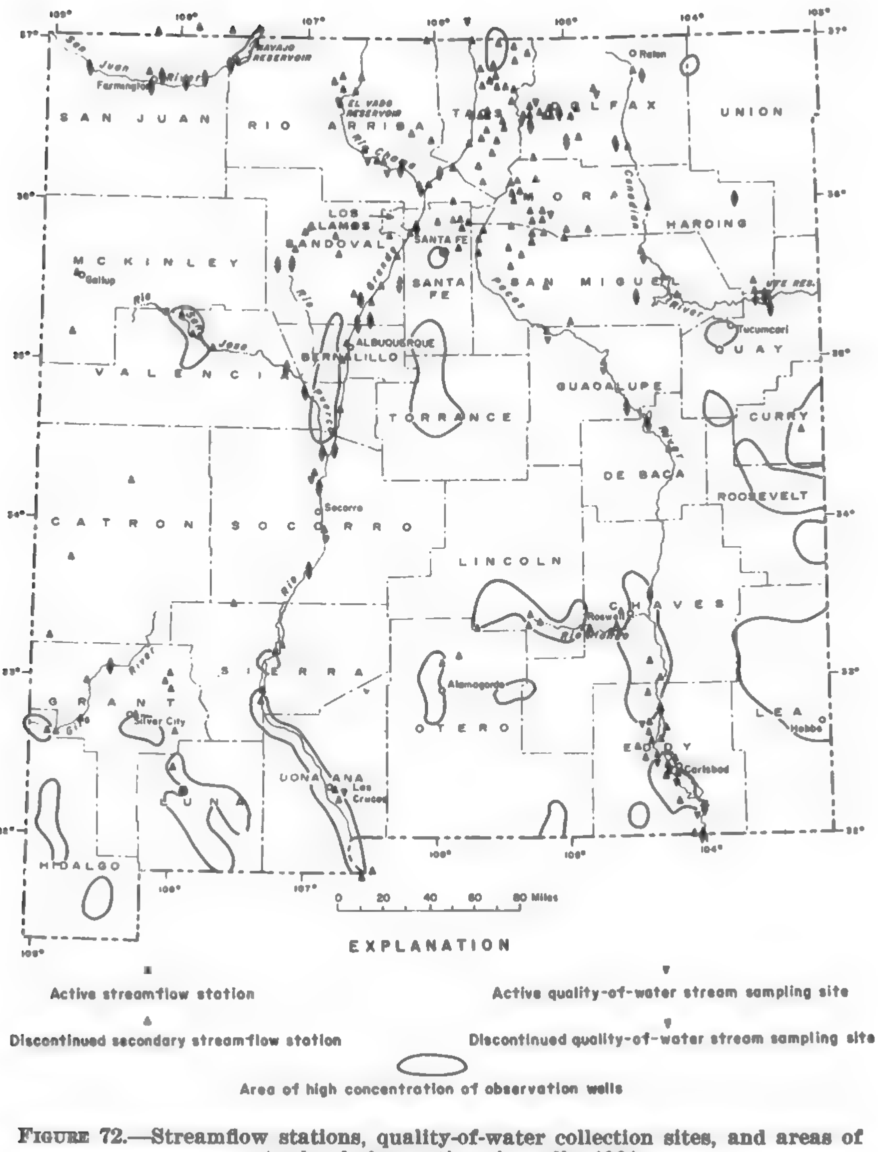


FIGURE 72.—Streamflow stations, quality-of-water collection sites, and areas of water-level observations in wells, 1964.

age of water in natural underground reservoirs are in the areas of least precipitation and runoff.

The chemical quality of both surface and ground water varies widely, and the quality of both is influenced by the types of rocks with which the water comes in contact. In general, the quality of surface water deteriorates downstream because it gains soluble minerals that enter the stream from irrigation and municipal return flow and from ground-water discharge.

The problem of chemical quality deterioration of surface water by the inflow of highly mineralized ground water is illustrated by an experiment underway on the Pecos River at Malaga Bend, south of Carlsbad. Studies showed that about 200 gpm (gallons per minute) of brine from an artesian aquifer brings about 420 tons of dissolved minerals (370 tons is sodium chloride) daily into the Pecos River along a 3-mile reach. The experiment is concerned with attempts to divert the brine moving toward the river by pumping 300 to 600 gpm from a well tapping the brine aquifer and delivering the pumpage to a nearby natural depression, where the water will evaporate and leave the salt as residue. The loss of water to the river will be small but the improvement in the quality of water will be large. If the experiment is successful, it will have application to other areas of saline inflow to streams in the State.

Saline ground water is prevalent in several parts of New Mexico, because many of the rocks in the State contain large amounts of readily soluble minerals and circulation of the water is slow in the aquifers. The gradual depletion of fresh water in some aquifers is resulting in the migration of saline waters into the fresh-water part of the aquifer. The ground-water supplies for the city of Roswell and for irrigation wells in that vicinity are rapidly becoming saline because of migration of saline waters. Other parts of the area from Roswell to Carlsbad may anticipate a similar chemical quality deterioration in their water supply unless means are found to stop the saline water encroachment.

Erosion of nearly barren land in large parts of the State adds large quantities of sediment to streams. Deposition of the sediment in reservoirs reduces their storage capacity and usefulness.

Waste, the undesirable residue of any process, must somehow be contained or diluted to safe concentrations to prevent contamination of water supplies. Waste whether it be solid, liquid, or gaseous is subject to transport to points where it may contaminate water supplies. Waste-laden water is common at many localities (fig. 73).

New Mexico is an important center for the extraction of raw radioactive material from its ore and for experimentation with nuclear energy. Mining and milling of raw material and experimentation processes produce large quantities of radioactive waste that must be disposed safely. At present, the mining and milling wastes are discharged to surface tanks where the liquid part is evaporated or injected into deeply-buried formations *and* the solid residue accumulates. Water supplies could be contaminated from these surface tanks.

At Los Alamos, low-level radioactive liquid effluents from laboratories are reduced. to off-site tolerance and discharged onto the land surface in small drainages tributary to the Rio Grande. Solid-state radioactive wastes from laboratories at Los Alamos and Albuquerque are buried in various waterproof containers. The long term problems of such wastes are under study and continuous monitoring.

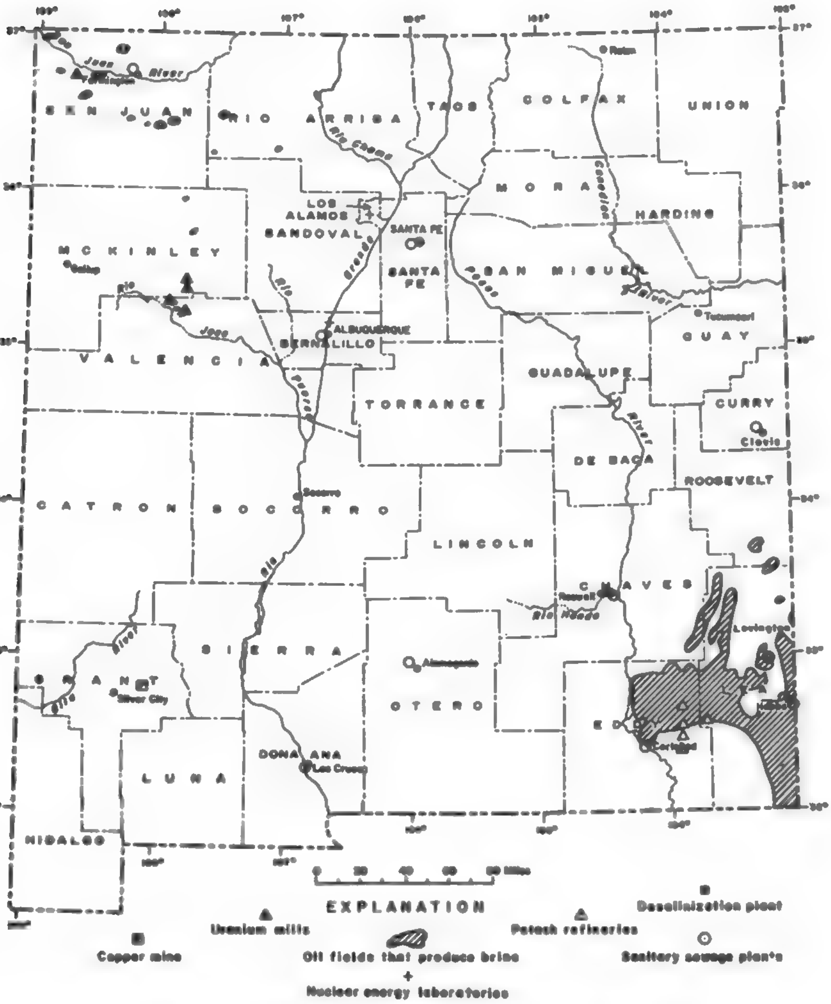


FIGURE 73.—Principal sources of waste water in New Mexico.

A waste-water disposal problem in southeastern New Mexico resulted from the large volume of highly mineralized water produced with oil in Lea, Chaves, and Eddy Counties. At present these brines are injected into aquifers at depth and seemingly are not contaminating fresh-water aquifers. It is not known whether this injection will result in a migration and eventual contamination of other aquifers.

Municipal waste treatment and disposal facilities in New Mexico discharged an average of 60.8 million gallons per day or 68,000 acre-feet per year in 1962, according to an inventory by the U.S. Department of Health, Education, and Welfare. Nearly a third of this is discharged by the city of Albuquerque into the Rio Grande; 75 other cities and towns have waste disposal facilities. The municipal sewage effluent contains more dissolved solids than the water from the original source. The sewage effluent also is charged with detergents which have been suspected of being injurious to some crops that are irrigated with water from the Rio Grande during low flow.

The use of insecticides and herbicides in New Mexico has been steadily increasing for many years. These chemicals can become water-borne and contaminate water supplies.

Several tens of thousands of acre-feet of water are lost annually because of water consumption by nonbeneficial vegetation that grows along the stream channels in the State. The amount lost will increase each year unless this vegetation is eradicated or other measures taken to replace nonbeneficial use by beneficial use.

ACKNOWLEDGMENTS

Much of the hydrologic data presented here has been abstracted from a report by Hale, W. E., and others (in press). Other personnel of the Water Resources Division, U.S. Geological Survey, who have contributed extensively to the preparation of the illustrations, tables, and other data used in this report include Durl E. Burkham, Alfred Clebsch, Jr., James B. Cooper, J. K. Culbertson, L. V. Davis, H. 0. Reeder, and F. D. Trauger. The New Mexico State Engineer Office and the New Mexico Institute of Mining and Technology, State Bureau of Mines and Mineral Resources Division, collaborated in planning the report and furnished part of the data. The material on water use in the minerals industry was abstracted from a U.S. Bureau of Mines report by Gilkey and Stotelmeyer (1964) .

SURFACE WATER

Streamflow data for many streams in New Mexico are summarized in figure 74 and in table 47. Streamflow is highly variable in New Mexico ; several large reservoirs are used to store water temporarily and thus make the supply more constant. The storage capacities of the larger reservoirs are summarized in table 48.

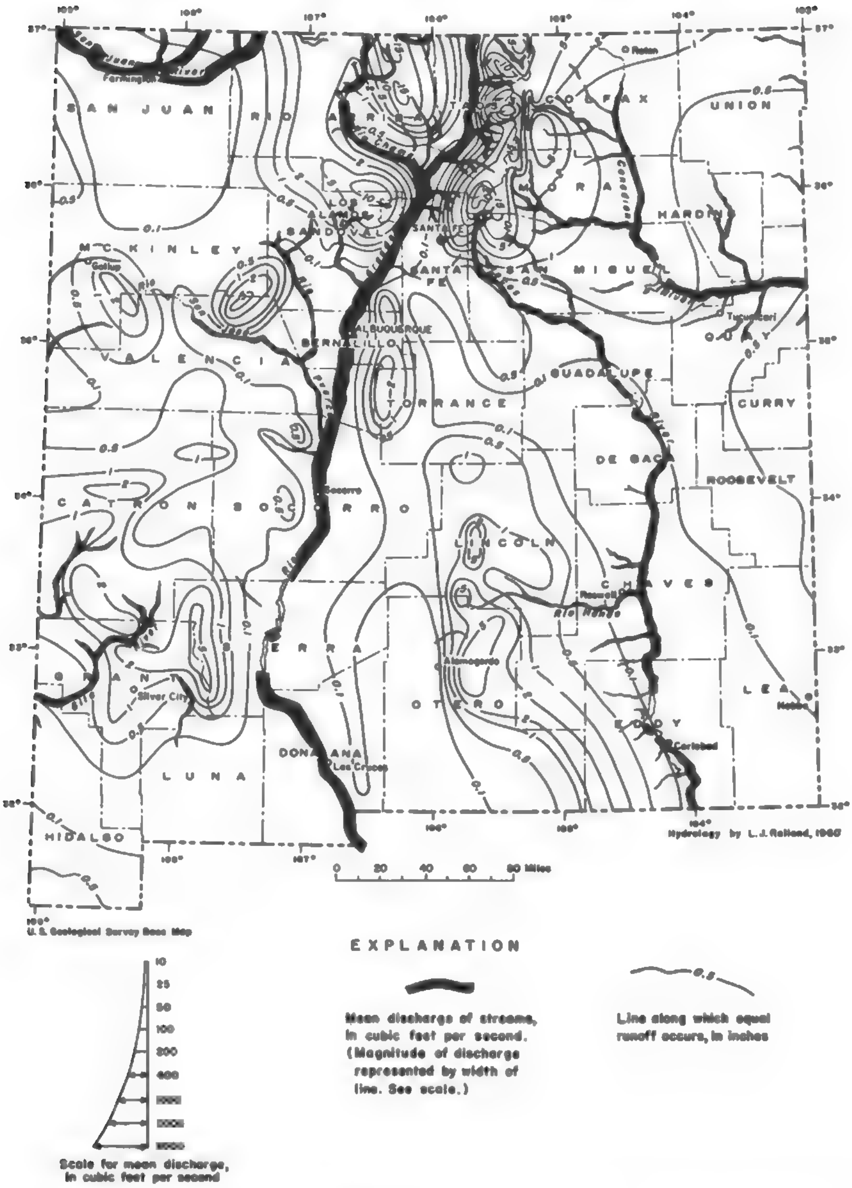
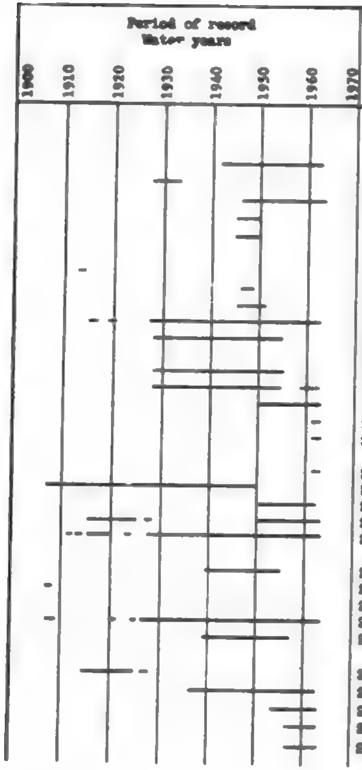


FIGURE 74.—Mean discharge of principal streams in cubic feet per second, and mean annual runoff in inches, in New Mexico.

TABLE 47.—*Summary of gaging station records*



Sta. No.	Gaging station	Drainage area (sq mi)	Average runoff acre-feet per year through 1963	Peak discharge Date	Peak discharge cfs	Peak discharge cfs per sq mi
	ARKANSAS RIVER BASIN:					
1535	Cimarron River near Guy	545	7,890	10- 5-54	8,500	15.6
1540	Cimarron River near Folsom	895	7,460	5-17-28	4,300	4.80
1990	Canadian River near Hebron	229	3,790	5-19-55	a6,860	30.0
1995	Chicorica Creek below Lake Maloya	26	2,140	5-18-55	2,230	85.8
2000	Chicorica Creek below East Fork near Raton	71	4,200	-	-	-
2005	Chicorica Creek near Raton	87	-	6-12-13	6,100	70.1
2015	Uña de Gato Creek near Hebron	224	-	7- 7-49	a718	3.21
2020	Chicorica Creek near Hebron	381	8,760	b	15,000	39.4
2030	Vermejo River near Dawson	301	14,260	8- 6-40	e9,000	29.9
2040	Moreno Creek at Eagle Nest	82	d	9- 1-46	240	2.93
2045	Cieneguilla Creek near Eagle Nest	56	d	4-23-42	500	8.93
2050	Six Mile Creek near Eagle Nest	11	d	4-11-37	125	11.36
2060	Cimarron Creek below Eagle Nest Dam	167	9,340	6-14-55	205	1.23
2062	McEvoy Creek near Eagle Nest	1.95	-	4-30-62	1.37	0.70
2063	Tolby Creek near Eagle Nest	8.5	-	4-20-62	27.3	3.21
2064	Clear Creek near Ute Park	7.44	-	5-13-62	28.3	3.80
2065	Cimarron Creek at Ute Park	260	e22,800	5-10-16	700	2.69
2070	Cimarron Creek near Cimarron	294	14,620	6- 6-58	580	1.97
2075	Ponil Creek near Cimarron	171	9,340	8- 8-29	5,200	30.4
2085	Rayado Creek at Sauble Ranch near Cimarron	65	10,280	4-23-42	850	13.1
2095	Rayado Creek near Miami	76	3,530	4-23-42	-	-
2100	Rayado Creek near Springer	77	-	-	-	-
2105	Urraca Creek near Cimarron	6.3	-	6-10-13	-	-
2110	Cimarron Creek at Springer	1,032	12,810	6- 6-58	6,250	6.06
2115	Canadian River near Taylor Springs	2,853	77,460	9-29-04	91,100	31.9
2120	East Fork Ocate Creek at Ocate	35	3,980	-	-	-
2140	Canadian River near Roy	4,066	93,390	4-23-42	63,800	15.7
2145	Rio Agua Negra near Holman	57	9,560	7-22-54	4,700	82.5
2146	Vigil Canyon at Holman	2.8	1,350	6- 6-58	87	31.1
2147	Agua Fria Creek near Holman	9.2	4,170	8- 6-59	138	15.0

2148	Rio de la Casa near Cleveland	23	10,790	8- 6-59	2,260	98.3
2155	Mora River at La Cueva	173	20,700	9-23-41	f1,530	8.84
2156	Cebolla River near Golondrinas	64	4,230	8- -52	9,300	145.3
2165	Mora River near Golondrinas	267	25,700	8-22-52	f14,000	52.4
2170	Coyote Creek below Black Lake	48	3,340	6- 6-58	913	19.0
2171	Coyote Creek above Guadalupita	71	7,310	6- 6-58	1,390	19.6
2175	Coyote Creek at Guadalupita	90	-	-	-	-
2180	Coyote Creek near Golondrinas	215	8,690	8-17-61	f4,050	18.8
2181	Mora River near Watrous	521	39,240	7- 8-62	f7,050	13.5
2187	Manuelitas Creek near Rociada	52	8,690	8-23-57	1,410	27.1
2200	Sapello River at Sapello	132	19,760	8- 4-57	6,160	46.7
2205	Sapello River at Los Alamos	144	-	6-11-13	11,400	79.1
2206	Sapello River near Watrous	213	12,920	8- 3-57	f5,860	27.5
2210	Mora River near Shoemaker	1,104	43,940	6- 3-48	f15,200	13.8
2215	Canadian River near Sanchez	6,015	169,400	9- 2-42	f87,800	14.6
2220	Canadian River near Bell Ranch	6,200	128,100	6- 3-57	f47,800	7.71
2225	Conchas River at Variadero	525	13,680	9- 1-42	44,000	84.1
2245	Canadian River below Conchas Dam	7,417	670,950	6- 3-57	f73,000	9.84
2260	Ute Creek near Bueyeros	620	12,160	8-16-53	39,000	62.9
2265	Ute Creek near Logan	2,075	21,570	1941	70,000	33.8
2270	Canadian River at Logan	11,141	e178,800	9-30-04	278,000	25.0
2271	Revuelto Creek near Logan	786	-	7- 9-60	26,700	34.0
	BRAZOS RIVER BASIN:					
0806	Running Water Draw near Clovis	109	1,480	9- 6-57	7,090	65.0
	RIO GRANDE BASIN:					
2475	San Antonio River at Ortiz, Colo.	110	19,260	4-15-57	1,750	15.9
2480	Los Pinos River near Ortiz, Colo.	167	90,500	5-12-41	3,160	18.9
2515	Rio Grande near Lobatos, Colo.	7,700	453,200	6- 8-05	13,200	1.71
2525	Costilla Creek above Costilla Dam	26	d	7-22-54	3,870	149
2530	Casias Creek near Costilla	19	d	6-11-57	122	6.42
2535	Santistevan Creek near Costilla	2.5	d	8-11-41	18	7.20
2540	Costilla Creek below Costilla Dam	55	12,310	5- 9-42	286	5.20
2545	Costilla Creek near Amalia	140	d	4-25-58	689	4.92
2550	Ute Creek near Amalia	12	d	6- 8-55	69	5.75
2555	Costilla Creek near Costilla	195	32,780	5-11-42	1,150	5.90
2605	Costilla Creek below diversion dam, at Costilla	197	d	7-22-54	525	2.66
2610	Costilla Creek at Garcia, Colo.	200	d	5-11-42	41,000	5.00
2625	Costilla Creek near Jaroso, Colo.	290	1,650	5-19-58	360	1.24
2630	Latir Creek near Cerro	10	4,610	6- 3-42	121	12.1
2635	Rio Grande near Cerro	8,440	249,000	6-22-49	9,740	1.15

TABLE 47.—*Summary of gaging station records*—Continued

Period of record Water years (1900–1970)	Sta. No.	Gaging station	Drainage area (sq mi)	Average runoff acre-feet per year through 1963	Peak discharge Date	Peak discharge cfs	Peak discharge cfs per sq mi
	2640	Red River near Red River	19.1	12,960	6-12-52	264	13.8
	2645	Red River below Zwergle damsite, near Red River	25.7	-	-	-	-
	2650	Red River near Questa	113	40,830	5-25-42	j886	7.84
	2660	Cabresto Creek near Questa	36.7	7,210	5-25-42	h200	5.45
	2665	Red River below Questa	180	61,470	-	-	-
	2670	Red River at mouth, near Questa	190	59,660	1-18-52	647	3.41
	2675	Rio Hondo near Valdez	36.2	26,420	5-13-41	541	14.9
	2680	Rio Hondo at Valdez	38	19,760	-	-	-
	2682	Rio Hondo at damsite, at Valdez	40.3	-	-	-	-
	2685	Rio Hondo at Arroyo Hondo	65.6	21,140	8-25-35	h1,200	18.3
	2690	Rio Pueblo de Taos near Taos	66.6	23,380	5-14-41	970	14.6
	-	Rio Pueblo de Taos and North Channel at Taos	80	18,390	5-14-41	950	11.9
	2710	Rio Lucero near Arroyo Seco	16.6	17,160	5-13-41	300	18.1
	2745	Rio Lucero below diversions, near Arroyo Seco	25	5,610	5-14-41	273	10.9
	2750	Rio Fernando de Taos, near Taos	71.7	6,760	-	-	-
	2753	Rio Pueblo de Taos near Ranchito	199	22,880	5-13-57	600	3.02
	2755	Rio Grande de Ranchos near Talpa	83	13,970	5-19-58	342	4.12
	2756	Rio Chiquito near Talpa	37.0	6,330	5-13-58	144	3.89
	2760	Rio Pueblo de Taos at Los Cordovas	359	42,710	5-14-41	1,830	5.10
	2763	Rio Pueblo de Taos below Los Cordovas	380	39,890	8-24-57	2,380	6.26
	2765	Rio Grande below Taos Junction Bridge, near Taos	9,730	542,300	6- 7-48	9,730	1.00
	2780	Pueblo Creek near Peñasco	-	43,360	5-13-41	1,440	-
	2785	Rio Santa Barbara near Llano	38	21,070	8-23-57	377	9.92
	2790	Embudo Creek at Dixon	305	39,150	8-22-46	2,180	7.15
	2795	Rio Grande at Embudo	10,400	737,300	6-19-03	16,200	1.56
	2815	Rio Chama near Chama	-	-	5- 7-16	k2,040	-
	2820	Rio Brazos near Brazos	-	-	5-14-15	k3,240	-
	2835	Rio Chama at Park View	405	248,300	5-21-26	k10,000	24.7
	2841	Rio Chama near La Puente	480	233,800	6- 7-57	k8,040	16.8
	2842	Willow Creek above Heron Reservoir, near Park View	112	-	-	-	-
	2843	Horse Lake Creek above Heron Reservoir, near Park View	45	-	-	-	-
	2845	Willow Creek near Park View	193	15,850	4-23-42	k4,500	23.3
	2855	Rio Chama below El Vado Dam	877	278,000	5-22-20	k9,000	10.3
	2865	Rio Chama above Abiquiu Reservoir	1,600	-	8- 3-63	1,800	1.12
	2870	Rio Chama below Abiquiu Dam	2,147	-	4-20-62	1,960	0.91

2875	Rio Chama near Abiquiu	2,284	293,200	7-28-52	k7,870	3.45
2880	El Rito near El Rito	50.5	13,180	4-23-42	1,240	24.6
2885	Rio Vallecitos at Vallecitos	-	-	5-21-12	970	-
2890	Rio Ojo Caliente at La Madera	419	53,280	4-21-58	3,140	7.49
2900	Rio Chama near Chamita	3,144	404,000	5-22-20	k15,000	4.78
2910	Santa Cruz River at Cundiyo	86	21,570	9-24-31	2,420	28.1
2915	Santa Cruz River at Riverside	188	7,020	7- 8-50	891	4.74
2920	Santa Clara Creek near Espanola	36.7	3,320	9-22-41	970	26.4
2948	Rio Nambe at Nambe Falls, near Nambe	25.1	-	-	-	-
2950	Rio Nambe near Nambe	38.2	7,670	7-31-55	5,580	[illegible]
3010	Pojoaque Creek at Pojoaque Bridge, near Nambe	-	9,560	7-31-55	10,300	-
3022	North Fork Tesuque Creek near Santa Fe	1.60	-	-	-	-
3023	Middle Fork Tesuque Creek near Santa Fe	.44	-	-	-	-
3024	South Fork Tesuque Creek near Santa Fe	.47	-	-	-	-
3025	Tesuque Creek above diversions, near Santa Fe	11.6	2,320	8-24-57	632	[illegible]4.5
3041	Little Tesuque Creek near Santa Fe	.37	-	-	-	-
3044	Little Tesuque Creek Tributary No. 2 near Santa Fe	.45	-	-	-	-
3050	Little Tesuque Creek near Santa Fe	8	927	7-19-38	186	[illegible]3.2
3055	Rio Tesuque at Tesuque	-	-	8-24-57	1,490	-
3130	Rio Grande at Otowi Bridge near San Ildefonso	14,300	1,137,000	5-23-20	24,400	1.71
3133	Rito de Los Frijoles near Los Alamos	8.9	-	4- 7-60	13	1.46
3145	Rio Grande at Cochiti	14,600	968,700	5-15-41	23,400	1.60
3160	Santa Fe River near Santa Fe	18.2	6,040	8-14-21	1,500	82.4
3180	Galisteo Creek at Domingo	640	7,230	8-20-35	m24,300	38.0
3190	Rio Grande at San Felipe	16,100	1,032,000	6-26-37	27,300	1.70
3195	Rito San Antonio near Los Alamos	-	-	7-10-50	-	-
3200	Jemez River near Jemez Springs	-	-	7-23-49	86	-
3205	East Fork Jemez River near Los Alamos	-	-	3- 6-50	4.0	-
3210	East Fork Jemez River near Jemez Springs	-	-	3-18-50	41	-
3215	Jemez River below East Fork near Jemez Springs	173	4	4-21-58	2,520	14.6
3220	Rio Las Vacas near Cuba	-	-	5-13-41	1,530	-
3230	Rio Guadalupe at Box Canyon, near Jemez	235	4	4-21-58	1,440	6.13
3235	Rio Guadalupe near Jemez Springs	239	51,620	5-13-41	3,190	13.3
3240	Jemez River near Jemez	470	46,530	5- -41	b6,000	12.8
3265	Jemez River at San Ysidro	854	-	7-28-39	4,100	4.80
3280	Jemez River above Jemez Canyon Dam	999	48,870	11-5,19-57	23,100	23.1
3290	Jemez River below Jemez Canyon Dam	1,040	37,280	8-29-43	16,300	15.7
3295	Rio Grande near Bernalillo	17,300	800,700	5-16-41	25,400	1.47

TABLE 47.—*Summary of gaging station records*—Continued

Period of record Water years (1900 1910 1920 1930 1940 1950 1960 1970)	Sta. No.	Gaging station	Drainage area (sq mi)	Average runoff acre-feet per year through 1963	Peak discharge		
					Date	cfs	cfs per sq mi
	3300	Rio Grande at Albuquerque	17,440	792,000	4-24-42	25,000	1.43
	3305	Tijeras Arroyo near Albuquerque	76.3	1,050	7-19-44	6,410	84.0
	3310	Rio Grande near Isleta	17,900	1,383,000	6-27-37	m14,200	.79
	3315	Rio Grande near Belen	18,230	587,100	4-24-42	23,100	1.27
	3320	Rio Grande near Bernardo	19,230	760,200	4-25-42	21,100	1.10
	3325	La Jara Creek near La Jara	-	-	6- 5-32	19	-
	3330	Rio Puerco near Cabezon	360	6,640	6-28-43	4,400	12.2
	3335	Rio Puerco at Cabezon	397	7,010	8- 2-46	2,440	6.15
	3340	Rio Puerco above Chico Arroyo, near Guadalupe	420	10,060	8-18-61	4,540	10.8
	3405	Chico Arroyo near Guadalupe	1,390	17,380	7-17-53	12,200	8.78
	3415	Bluewater Creek below Bluewater Dam	201	1,560	7-1,3-52	58	.29
	3420	Bluewater Creek near Bluewater	209	7,150	7- -19	p4,000	19.1
	3430	Bluewater Creek at Grants	1,020	3,560	8-28-52	p1,760	1.73
	3435	Rio San Jose near Grants	1,070	4,910	9-20-63	1,400	1.31
	3455	Rio San Jose near San Fidel	1,080	4,990	5-1,4-41	418	.39
	3480	Rio San Jose near Casa Blanca	-	5,660	7-26-37	1,330	-
	3485	Encinal Creek near Casa Blanca	-	-	-	-	-
	3495	Paguate Creek near Laguna	-	-	8- 1-37	174	-
	3505	Rio San Jose near Laguna	-	-	8- 1-37	3,400	-
	3515	Rio San Jose at Correo	2,530	8,400	8-21-35	q11,000	4.35
	3525	Rio Puerco at Rio Puerco	5,460	44,740	9-23-29	37,700	6.90
	3530	Rio Puerco near Bernardo	6,220	37,790	9-23-29	35,000	5.62
	3540	Rio Salado near San Acacia	1,380	9,700	8-12-29	27,400	19.9
	3550	Rio Grande at San Acacia	26,770	795,600	9-23-29	h50,000	1.87
	3555	Rio Grande at San Antonio	27,400	391,700	10-11-04	50,000	1.82
	3585	Rio Grande at San Marcial	27,700	970,800	10-11-04	50,000	1.81
	3595	Rio Grande at narrows in Elephant Butte Reservoir	28,500	479,300	9- 3-57	f8,500	.30
	3600	Alamosa River near Monticello	403	5,920	8-21-36	10,300	25.6
	3610	Rio Grande below Elephant Butte Dam	29,450	758,700	5-22-42	r8,220	.28
	3625	Rio Grande below Caballo Dam	30,700	675,500	5-20-42	r7,650	.25
	3636	Las Cruces Arroyo near Las Cruces	13.5	65.2	8-23-59	1,060	78.5
	3640	Rio Grande at El Paso, Texas	32,207	636,400	6-12-05	24,000	.75

	PECOS RIVER BASIN:					
3780	Pecos River near Cowles	160	89,770	5-27-12	1,800	11.2
3785	Pecos River near Pecos	189	72,400	9-21-29	4,500	23.8
3790	Pecos River near San Jose	539	-	7-14-39	2,220	4.12
3792	Tecolote Creek near San Pablo	83	-	8-17-61	10,900	131
3795	Pecos River near Anton Chico	1,050	103,500	9-30-04	73,000	69.5
3800	South Fork Gallinas River near El Porvenir	25	10,570	4- -19	-	-
3805	Gallinas River near Montezuma	84	14,770	8- 4-57	5,400	64.3
3810	Gallinas River at Montezuma	87	14,190	9-29-04	11,600	133
3820	Gallinas River near Lourdes	313	10,500	8-17-61	6,680	21.3
3825	Gallinas River near Colonias	610	13,320	6- 1-37	26,700	43.8
3830	Pecos River at Santa Rosa	2,650	107,900	6- 2-37	55,200	20.8
3835	Pecos River near Puerto de Luna	3,970	166,500	6- 3-37	60,000	15.1
3845	Pecos River below Alamogordo Dam	4,390	170,900	9- 1-42	f42,800	9.73
3855	Pecos River near Fort Sumner	5,300	173,000	9-30-04	53,000	10.0
3860	Pecos River near Acme	11,380	157,800	5-28-37	53,300	4.68
3870	Rio Ruidoso at Hollywood	120	7,670	7-26-57	1,070	8.92
3880	Rio Ruidoso at Hondo	290	13,760	9-29-41	12,400	42.8
3885	Rio Bonito at Angus	45.5	-	4-22-31	121	2.66
3895	Rio Bonito at Hondo	295	7,460	9-29-41	11,000	37.3
3901	Rio Hondo at Picacho	715	-	5-14-58	3,510	4.91
3905	Rio Hondo at Diamond A. Ranch near Roswell	947	18,970	9-22-41	27,000	28.5
3936	North Spring River at Roswell	19.5	7.2	8-31-63	101	5.18
3945	Rio Felix at old highway bridge, near Hagerman	932	12,520	10- 7-54	74,000	79.4
3950	Rio Felix near Hagerman	934	20,710	5-29-37	23,600	25.3
3955	Pecos River near Lake Arthur	14,760	211,400	5-30-37	51,500	3.49
3960	Cottonwood Creek near Lake Arthur	199	4,180	-	-	-
3965	Pecos River near Artesia	15,300	246,900	10- 2-04	b60,000	3.92
3976	Rio Peñasco near Dunken	580	4,230	9-22-41	70,000	121
3985	Rio Peñasco at Dayton	1,070	3,620	9-22-41	b60,000	56.1
4000	Four Mile Draw near Lakewood	265	1,010	10- 7-54	7,650	28.9
4010	Pecos River below McMillan Dam	16,990	77,460	e	b40,000	2.35
4015	Pecos River below Major Johnson Springs	-	-	-	-	-
4020	Pecos River at Damsite 3, near Carlsbad	17,980	131,800	5-22-41	60,000	3.34
4040	Pecos River below Avalon Dam	18,080	27,660	10- 7-54	41,000	2.27
4050	Pecos River at Carlsbad	18,100	159,300	10- 2-04	90,000	4.97
4055	Black River above Malaga	343	9,050	9-21-41	33,000	96.2
4060	Black River at Malaga	360	-	-	-	-
4065	Pecos River near Malaga	19,190	185,200	9-21-41	65,700	3.32
4070	Pecos River at Pierce Canyon Crossing near Malaga	19,260	150,600	-	-	-
4075	Pecos River at Red Bluff	19,540	165,800	5-24-41	92,600	2.69
4085	Delaware River near Red Bluff	689	10,350	10- 2-55	81,400	118

TABLE 47.—*Summary of gaging station records*—Continued

Period of record Water years (1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970)	Sta. No.	Gaging station	Drainage area (sq mi)	Average runoff acre-feet per year through 1963	Peak discharge Date	Peak discharge cfs	Peak discharge cfs per sq mi
		MIMBRES RIVER BASIN:					
	4765	Bear Canyon near Mimbres	14.5	579	9-29-41	123	8.48
	4770	Mimbres River near Mimbres	152	7,160	8- 2-52	1,560	10.3
	4775	Mimbres River near Faywood	460	9,480	8- 4-39	20,000	43.5
	4776	San Vicente Arroyo at Silver City	26.5	594	8-16-63	t4,680	176
		TULAROSA VALLEY BASIN:					
	4806	Three Rivers near Three Rivers	6.9	-	5-15-58	211	30.6
	4807	Indian Creek near Three Rivers	6.8	-	6-17-58	307	45.1
	4808	Indian Creek flume near Three Rivers	-	-	10-12-58	13	-
	4809	Indian Creek at mouth near Three Rivers	10.9	-	7-26-57	1,780	163
	4815	Rio Tularosa near Bent	120	7,000	7-12-50	2,360	19.7
	4820	Rio Tularosa near Tularosa	140	11,080	9- 3-38	9,640	68.9
	4855	Alamo Creek at Wood Ranch near Alamogordo	-	1,370	7-17-33	7.7	-
		SAN JUAN RIVER BASIN:					
	3464	San Juan River near Caracas, Colo.	1,230	-	4-20-62	3,920	3.18
	3498	Piedra River near Arboles, Colo.	629	-	3-29-63	1,640	2.61
	3505	San Juan River at Rosa	1,990	871,700	6-29-27	k25,000	12.6
	3540	Los Pinos River at Ignacio, Colo.	448	u154,900	6-29-27	k7,000	15.6
	3545	Los Pinos River at La Boca, Colo.	510	137,600	7-27-57	6,400	12.5
	3550	Spring Creek at La Boca, Colo.	58	20,340	7-19-57	362	6.24
	3555	San Juan River near Archuleta	3,260	851,400	7-27-57	18,900	5.80
	3565	San Juan River near Blanco	3,560	1,047,000	8-11-29	k25,000	7.02
	3570	San Juan River at Bloomfield	5,410	1,043,000	10- 6-11	80,000	14.8
	3635	Animas River near Cedar Hill	1,090	653,000	6-19-49	k13,100	12.0
	3640	Animas River at Aztec	1,270	866,600	10- 6-11	30,000	23.6
	3645	Animas River at Farmington	1,360	688,500	6-29-27	k25,000	18.4
	3650	San Juan River at Farmington	7,240	1,829,000	6-29-27	k68,000	9.39
	3665	La Plata River at Colorado-New Mexico State line	331	24,760	8-24-27	4,750	14.4
	3670	La Plata River at La Plata	351	14,330	10- 6-04	8,000	22.8

3675	La Plata River near Farmington	583	18,680	-	-	-
3680	San Juan River at Shiprock	12,900	1,683,000	8-11-29	v80,000	6.20
	LITTLE COLORADO RIVER BASIN:					
3860.5	Largo Creek near Mangas	63	-	2- 1-65	258	4.10
3870	Zuni River at Blackrock	692	19,220	-	-	-
3955	Puerco River at Gallup	558	6,200	8- 6-59	9,270	16.6
	GILA RIVER BASIN:					
4300	Gila River near Silver City	1,600	128,100	10-14-16	-	-
4305	Gila River near Gila	1,864	90,500	9-29-41	25,400	13.6
4310	Gila River near Cliff	2,490	86,150	9-29-41	-	-
4315	Gila River near Red Rock	2,829	141,200	9-29-41	40,000	14.1
4320	Gila River below Blue Creek near Virden	3,203	118,700	9-29-41	41,700	13.0
-	Gila River at Virden Bridge near Duncan, Ariz.	3,290	-	8-11-30	7,400	2.25
4380	Gila River at New Mexico-Arizona State line near Virden	3,360	110,000	9-29-41	39,500	11.8
4426.8	San Francisco River near Reserve	350	-	9- 9-63	806	2.30
4430	San Francisco River near Alma	1,560	-	11-26-05	25,000	16.0
4435	Whitewater Creek near Mogollon	34	12,600	-	-	-
4440	San Francisco River near Glenwood	1,653	45,250	1-13-49	v7,800	4.72
4445	San Francisco River at Clifton, Ariz.	2,766	131,000	1-19-16	v90,000	32.5
4540	San Simon Creek near Rodeo	497	2,100	-	-	-

a Maximum recorded; a greater discharge occurred in April, 1942.
b Probably occurred Apr. 23, 1942.
c Maximum recorded; peak discharge of Aug. 2, 1921, probably exceeded 10,000 cfs.
d Seasonal records; average discharge not available.
e Since completion of Eagle Nest Dam.
f Maximum recorded; a greater discharge occurred Sept. 29 or 30, 1904.
g Since completion of Conchas Dam.
h Equal to or greater than.
j A greater discharge may have occurred June 15, 1921.
k Maximum recorded; a greater flood occurred Oct. 5 or 6, 1911.
m A greater discharge may have occurred on June 26, 1957.
n Maximum for period 1936-38.
p Maximum recorded; a greater flood occurred Sept. 6, 1909, when Bluewater dam washed out.
q A greater discharge may have occurred Sept. 23, 1929.
r Maximum daily discharge since completion of dam.
s August 1895, Oct. 2, 1904, July 25, 1905, Apr. 17, 1915, Aug. 7, 1916, and May 30, 1957.
t Maximum recorded; the flood of July 21, 1895, probably exceeded 10,000 cfs.
u Since completion of Vallecitos Dam.
v Maximum recorded; the flood of Oct. 6, 1911, may have exceeded 130,000 cfs.
w Maximum recorded; a greater flood occurred Oct. 14, 1916.

TABLE 48.—*Reservoirs in New Mexico having a usable capaci ty of 30,000 acre-feet or more*

Name of reservoir and stream	Type of dam	Location—Township and range	Drainage area (square miles)	Year completed	Original capacity (acre-feet)	Dead storage (acre-feet)	Present capacity (acre-feet)	Usable capacity (acre-feet)	Surface area (acres)	Use [1]
Abiquiu, Rio Chama	Earthfill	T. 23 N., R. 5 E.	2,417	1963	1,225,000	0	1,225,000	1,225,000	12,434	FS
Alamogordo, Pecos River	do	T. 5 N., R. 24 E.	4,390	1937	157,000	0	122,100	122,100	4,570	IR
Bluewater Lake, Bluewater Creek	Concrete	T. 12 N., R. 12 W.	201	1927	----------	3.4	38,510	38,510	1,750	IR
Caballo, Rio Grande	Earthfill	T. 16 S., R. 4 W.	30,700	1938	345,900	0	344,000	344,000	11,613	FIR
Conchas, Canadian River	Concrete	T. 14 N., R. 26 E.	7,409	1939	399,300	90,800	370,200	279,400	9,594	FIR
Eagle Nest, Cimarron Creek	do	T. 27 N., R. 16 E.	167	1918	79,120	0	79,120	79,120	2,426	IR
Elephant Butte, Rio Grande	do	T. 13 S., R. 3 W.	29,445	1916	2,639,000	0	2,195,000	2,195,000	36,584	IPR
El Vado, Rio Chama	Rockfill	T. 28 N., R. 2 E.	873	1935	196,800	0	194,500	194,500	3,230	IR
Jemez Canyon, Jemez Creek	Earthfill	T. 14 N., R. 4 E.	1,034	1953	117,200	0	113,100	113,100	2,880	FS
Lake McMillan, Pecos River	do	T. 20 S., R. 26 E.	16,990	1893	90,000	0	39,430	39,430	5,680	IR
Morgan Lake, offstream reservoir, San Juan River	do	T. 29 N., R. 16 W.	[2] 4	1962	39,000	----------	39,000	39,000	1,260	PR
Navajo, San Juan River	do	T. 30 N., R. 7 W.	3,240	1962	1,709,000	12,600	1,709,000	1,696,400	15,650	FIR
Two Rivers, Rio Hondo	do	T. 12 S., R. 22 E.	1,027	1963	167,900	0	167,900	167,900	4,086	FS
Ute, Canadian River	do	T. 13 N., R. 33 E.	11,140	1963	109,600	20,700	109,600	88,900	4,130	FMRS

[1] Use: F, flood control; I, irrigation; P, power production; R, recreation; S, sediment retention; M, municipal and industrial.
[2] Drainage area tributary to reservoir.

The dissolved-solids discharge of streams is related to distribution of rainfall, weathering rate of rocks, and solubility of minerals in the watershed, vegetal cover, irrigation return, waste disposal, and seepage from ground-water aquifers. Disolved solids from irrigation return and ground-water seepage constitute the major part of solutes discharged by the Canadian and Pecos Rivers; irrigation return and tributary inflow account for the major part of solutes discharged by the Rio Grande and San Juan Rivers. The disolved solids discharge of major streams in New Mexico is summarized in figure 75 and table 49.

The temperature of water in streams is critical for many industrial uses; temperature data from selected stations are summarized in table 50.

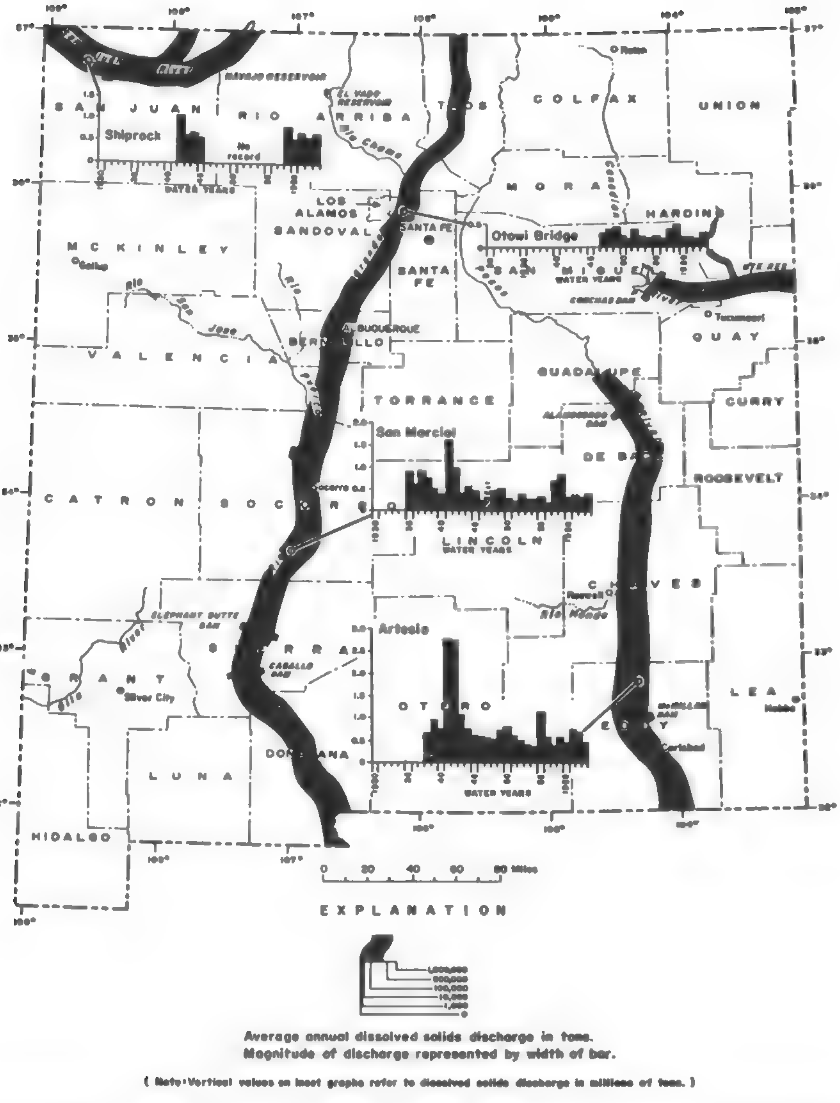


Figure 75.—Average annual dissolved solids discharge in streams and dissolved solids discharge in years at selected stations in New Mexico.

TABLE 50.—*Mean monthly water temperatures in degrees Fahrenheit for selected stations in New Mexico*

Station	Period of record	October	November	December	January	February	March	April	May	June	July	August	September
Rio Chama near Chamita	1951–59	58	44	36	36	41	46	53	59	67	72	72	68
Rio Grande at Otowi	1949–59	55	43	36	37	39	45	52	58	66	71	70	64
Rio Grande near Bernalillo	1948–59	54	40	36	37	39	44	50	58	66	70	70	62
Rio Grande at San Marcial	1949–59	64	49	43	42	46	53	62	68	76	79	78	72
Pecos River near Artesia	1949–59	64	52	45	45	49	55	63	71	78	81	80	75
San Juan River at Shiprock	1951–59	54	42	36	36	40	47	54	60	68	73	74	67

The quantity of suspended sediment carried in a stream at any point is related primarily to erosion; unconsolidated soils containing fine sands and clays are easily eroded. High-intensity thundershowers over drainage areas cause much more erosion than gentle rains while vegetation retards erosion. Several stations for measuring the suspended-sediment discharge are operated on major streams. The data from these stations are summarized in figure 76 and in table 51.

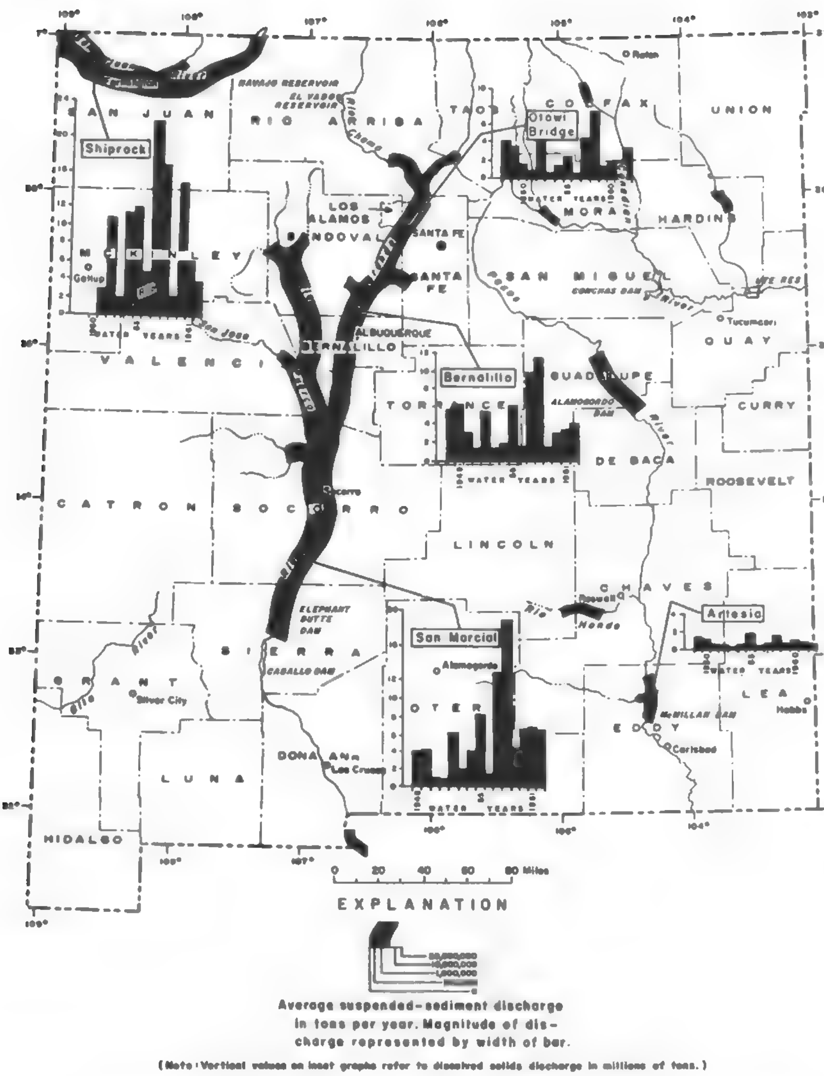


FIGURE 76.—Average annual suspended-sediment discharge of streams and suspended-sediment discharge by years at selected stations in New Mexico.

TABLE 51.—*Summary of suspended-sediment station records for streams in New Mexico*

Period of record - Water years (1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970)	Sta. No.	Station	Frequency of sampling	Daily suspended-sediment concentration (ppm) Max.	Daily suspended-sediment concentration (ppm) Min.	Suspended-sediment load (tons/day) Max.	Suspended-sediment load (tons/day) Min.
		ARKANSAS RIVER BASIN:					
	1535	Cimarron River near Guy	M	-	-	-	-
	2015	Chicorica Creek near Hebron	D	28,400	NF	79,800	0
	2030	Vermejo River near Dawson	D	39,800	NF	94,500	0
	2180.5	Mora River at Loma Parda	D	-	4	e200,000	.5
	2260	Ute Creek near Bueyeros	D	21,700	NF	840,000	0
	2640	Red River near Red River	M	153	1	13	.018
	2645	Red River below Zwergle damsite, near Red River	M	-	-	-	-
	2675	Rio Hondo near Valdez	M	76	.2	3.09	.01
	2682	Rio Hondo at damsite, at Valdez	M	-	-	-	-
		RIO GRANDE BASIN:					
	2755	Rio Grande de Ranchos near Talpa	M	338	3	99.4	.04
	2795	Rio Grande at Embudo	D	10,200	4	51,000	4
	2845	Willow Creek near Park View	M	6,120	7	15,300	.026
	2865	Rio Chama above Abiquiu Reservoir	D	-	-	-	-
	2870	Rio Chama below Abiquiu Dam	D	-	-	-	-
	2875	Rio Chama near Abiquiu	D	58,000	3	248,000	<.5
	2900	Rio Chama near Chamita	D	55,500	NF	209,000	0
	2943	Rio Nambe at Nambe Falls, near Nambe	M	-	-	-	-
	2950	Rio Nambe near Nambe	M	986	1	37.4	.01
	3130	Rio Grande at Otowi Bridge, near San Ildefonso	D	42,600	11	366,000	3
	3145	Rio Grande at Cochiti	W	44,700	6	186,000	<.5
	3180	Galisteo Creek at Domingo	D	96,300	NF	1,600,000	0
	3190	Rio Grande at San Felipe	W	38,300	84	86,200	22
	3290	Jemez River below Jemez Canyon Dam	D	118,000	NF	167,000	0
	3291	Piedra Lisa Arroyo near Bernalillo	D	13,600	NF	570	0
	3295	Rio Grande near Bernalillo	D	75,000	NF	1,680,000	0
	3300	Rio Grande at Albuquerque	W	62,300	11	610,000	<.5
	3315	Rio Grande near Belen	W	23,900	24	88,200	1
	3320	Rio Grande near Bernardo	D	-	-	348,000	0
	3340	Rio Puerco below Cabezon	D	166,000	NF	730,000	0

3405	Chico Arroyo near Guadalupe	D	113,000	NF	1,220,000	0
3515	Rio San Jose at Correo	D	120,000	NF	364,000	0
3525	Rio Puerco at Rio Puerco	D	210,000	NF	1,800,000	0
3530	Rio Puerco near Bernardo	D	230,000	NF	2,240,000	0
3540	Rio Salado near San Acacia	D	182,000	NF	795,000	0
3548	Rio Grande Conveyance Channel at San Acacia	D	131,000	NF	423,000	0
3549	Rio Grande Floodway at San Acacia	D	196,000	NF	1,760,000	0
3555	Rio Grande at San Antonio	D	122,000	NF	1,200,000	0
3580	Rio Grande Conveyance Channel below heading near San Marcial	D	138,000	NF	294,000	0
3581	Rio Grande (Tiffany Channel) at San Marcial	D	41,700	NF	40,600	0
3583	Rio Grande Conveyance Channel at San Marcial	D	122,000	NF	356,000	0
3584	Rio Grande Floodway at San Marcial[a]	D	117,000	NF	966,000	0
3637	Tortugas Arroyo near Las Cruces	D	-	-	-	-
3640	Rio Grande at El Paso	D	-	-	-	-
	PECOS RIVER BASIN:					
3830	Pecos River at Santa Rosa	D	30,800	8	276,000	<.5
3834	Pecos River at Puerto de Luna	D	59,200	20	1,510,000	4
3905	Rio Hondo at Diamond "A" Ranch, near Roswell	D	64,900	NF	630,000	0
3965	Pecos River near Artesia	D	20,900	NF	183,000	0
3985	Rio Penasco at Dayton	D	30,000	NF	600,000	0
	SAN JUAN RIVER BASIN:					
3430	Rio Blanco near Pagosa Springs, Colo.	M	986	1	1,580	.04
3443	Navajo River above Chromo, Colo.	M	483	2	717	.07
3505	San Juan River at Rosa	D	14,700	3	77,400	3
3555	San Juan River near Archuleta	D	34,200	1	522,000	<.5
3565	San Juan River near Blanco	D	51,300	8	418,000	1
3570	San Juan River at Bloomfield	D	101,000	7	1,110,000	4
3645	Animas River at Farmington	D	36,100	1	337,000	<.5
3680	San Juan River at Shiprock	D	86,000	2	1,700,000	1
	GILA RIVER BASIN:					
4300	Gila River near Gila	D	17,500	1	14,800	<.5
4440	San Francisco River near Glenwood	M	2,470	10	190	.28
4445	San Francisco River at Clifton, Ariz.	M	-	-	-	-

Note: NF, no flow [a] Prior to 1954, published as Rio Grande at San Marcial e Estimated

GROUND WATER

Sedimentary rocks (mainly sandstone, limestone, and unconsolidated sand and gravel) are the most productive aquifers or water-bearing beds in New Mexico. Evaporite rocks (mainly anhydrite and gypsum) are relatively impermeable, but may be productive where they are leached or fractured. Volcanic rocks in New Mexico are not good aquifers, but locally they may yield large quantities of water. Intrusive igneous and metamorphic rocks generally are poor aquifers. Widespread thick aquifers will yield more water than equally permeable thin, discontinuous aquifers.

The intensity of rock deformation in New Mexico varies considerably, from gently dipping beds in the plains and plateaus to vertical, i or even overturned beds in the mountains. An aquifer that can be tapped by shallow wells in one area may be hundreds of feet below the land surface a few miles away, owing to steep dip of the beds or large vertical displacement along faults. A rock unit may be a good aquifer at one place and not at another because it is fractured in one area and not in the other.

The distribution of the principal types of aquifers is shown in figures 77-79. The areas in which small, moderate, and large yields of ground water can be obtained are shown in figure 80. In the higher-yield areas supplies of more than 1,000 gallons per minute from individual wells are common. These are the areas in which the aquifers are chiefly alluvium or limestone.

The depth to ground water in much of the State is less than 500 feet. Locally, the depth exceeds 500 feet (fig. 81), particularly in northwestern Eddy County, in the high country in northern Grant and southern Catron Counties, and along the west margin of the Rio Grande Valley northward from Albuquerque to Los Alamos. In one small area near the southwest corner of Los Alamos County the depth to water probably is more than 1,500 feet.

Withdrawal of large amounts of ground water in parts of New Mexico has reduced the amount of water in storage; this is called water mining. A large amount of water is in ground storage and is available for beneficial use. The result of mining is a decline in water levels; the greatest decline occurs in highly pumped areas (figs. 82-85) .

In some basins the rate of storage depletion is reduced or ceases when the rate of natural discharge is reduced or when additional recharge is induced. Unfortunately, reducing the natural discharge or inducing additional recharge generally cause a diminution of streamflow. This results in interference with surface-water rights.

In large parts of New Mexico fresh ground water (water containing less than 1,000 parts per million of dissolved solids) is scarce (fig. 86). Water of good chemical quality generally is found in rocks that consist largely of silica or silicate minerals, such as the alluvium of many valleys and the High Plains, granitic rocks in mountainous areas, and sandstone. Near the outcrops of all rocks that form aquifers the water is of better quality than at places where the rocks are deeply buried. Shallow water of good quality generally is underlain by saline water at some depth.

Slightly saline water containing 1,000 to 3,000 parts per million dissolved solids is frequently used for drinking, irrigation, and industrial purposes in New Mexico where water of better quality is not avail-

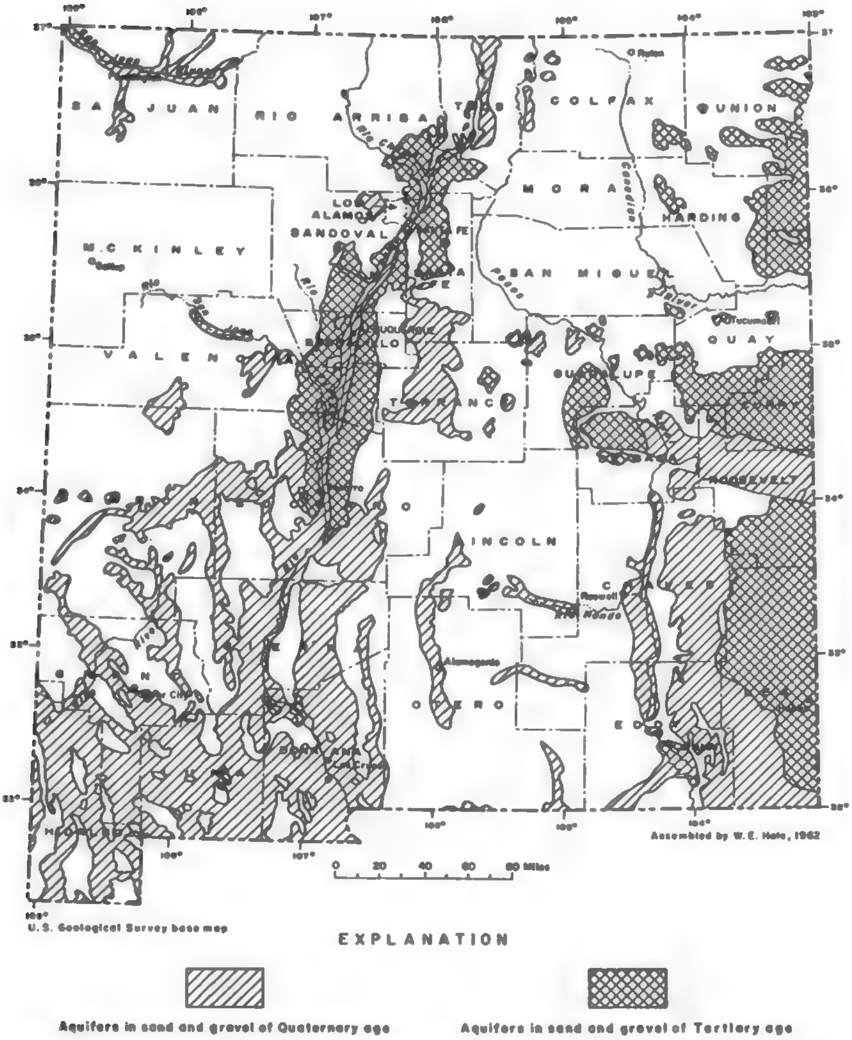


FIGURE 77.—Principal sand and gravel (alluvial) aquifers in New Mexico.

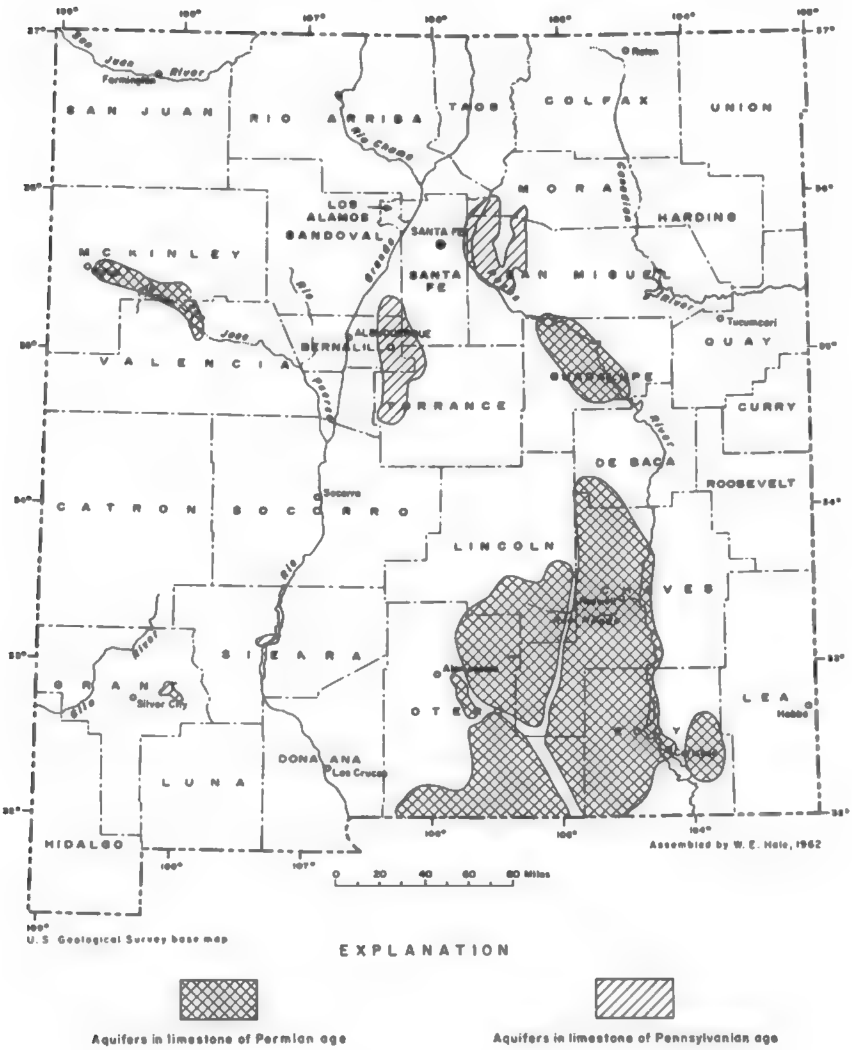


FIGURE 78.—Principal limestone aquifers in New Mexico.

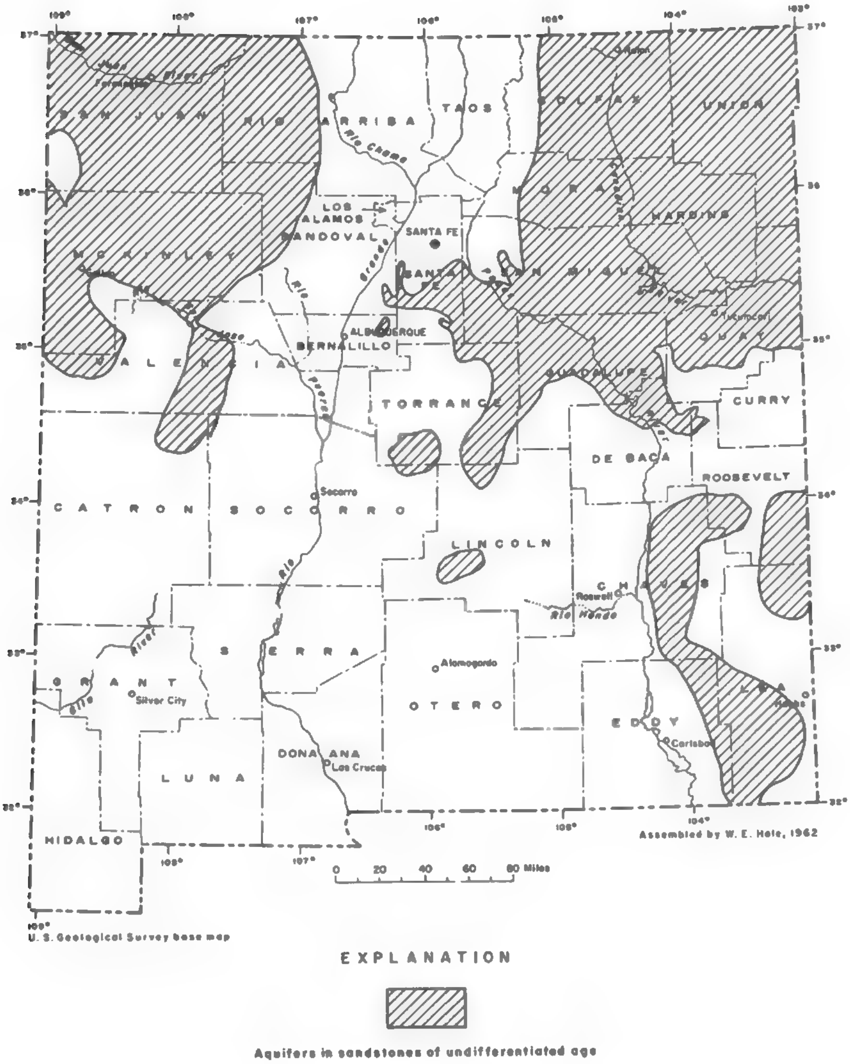


FIGURE 79.—Principal sandstone aquifers in New Mexico.

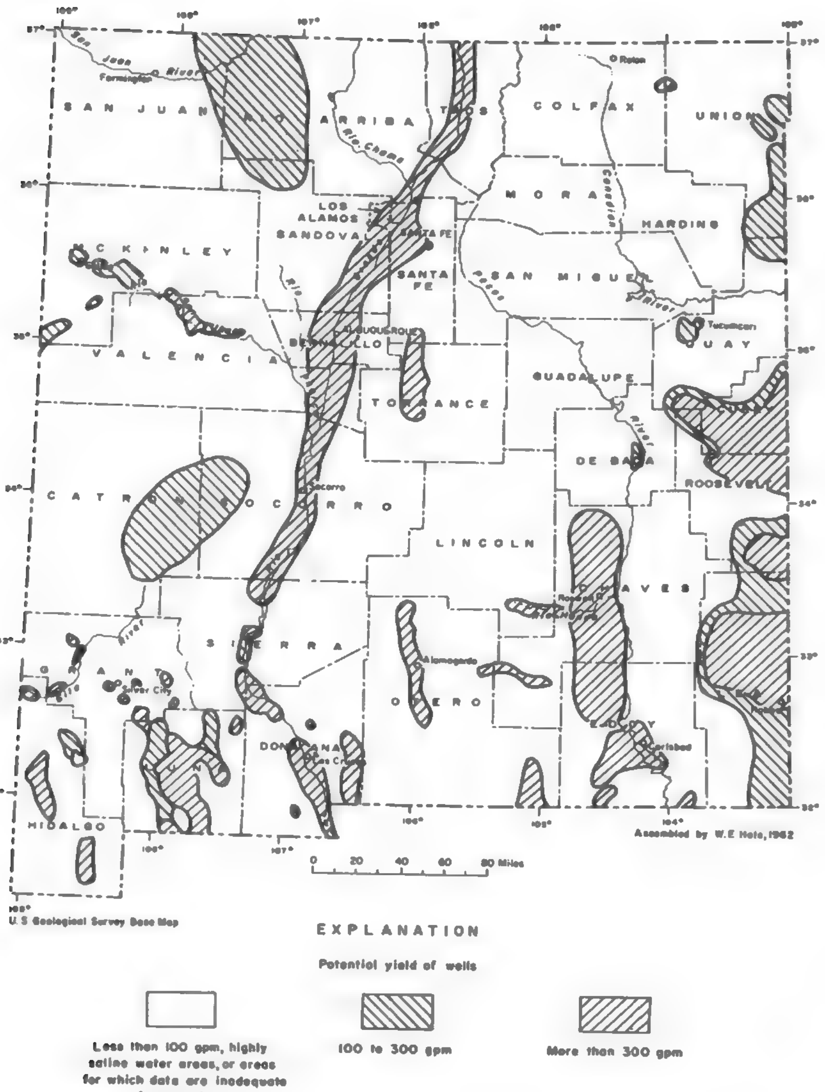


FIGURE 80.—General availability of relatively fresh ground water in New Mexico.

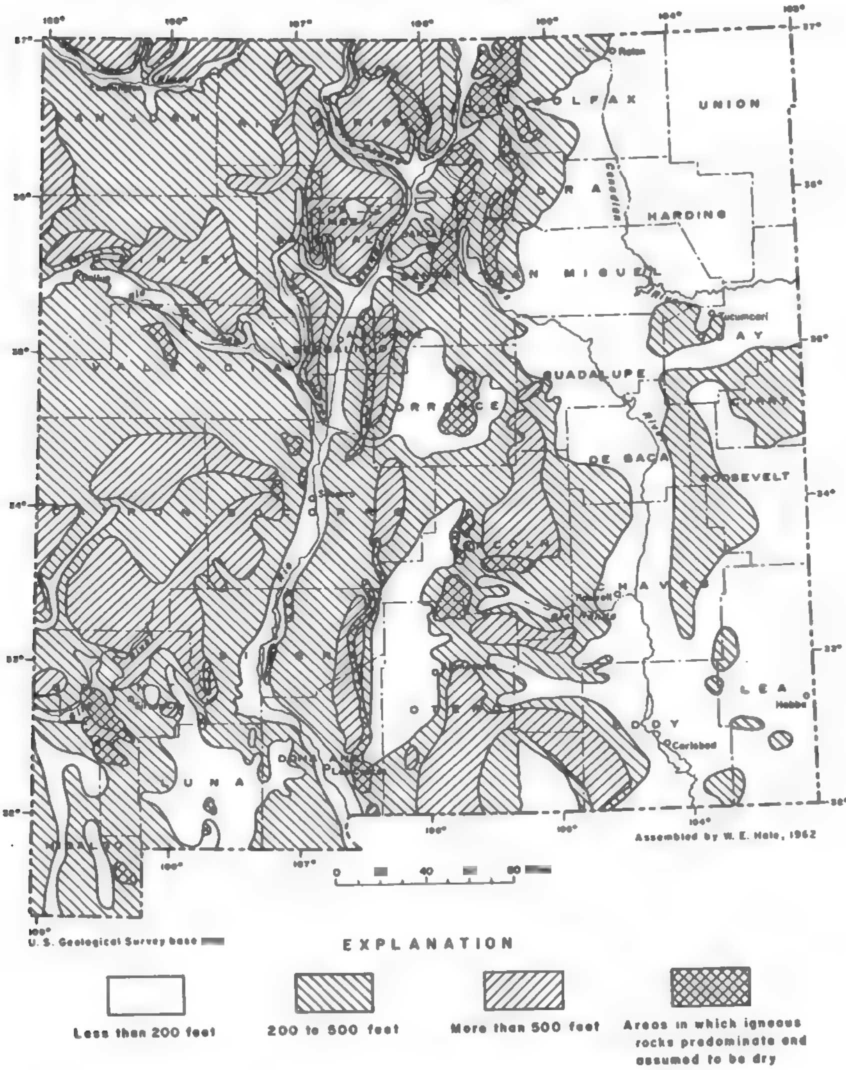


FIGURE 81.—Depth to ground water in New Mexico.

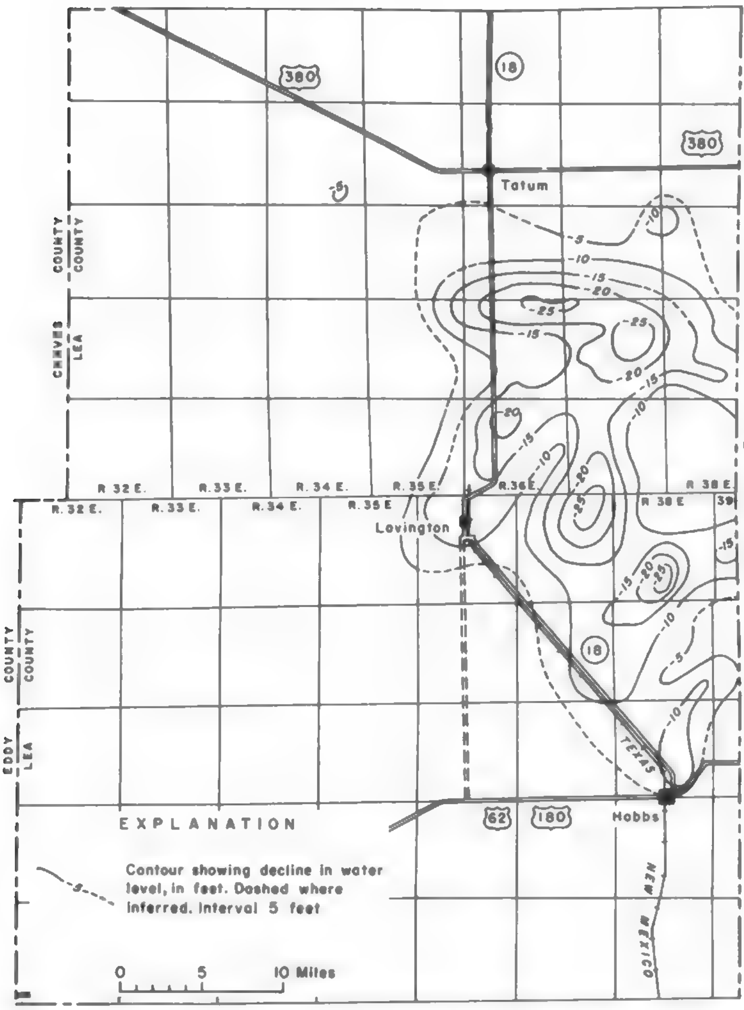


FIGURE 82.—Decline of ground water level in Tatum-Lovington-Hobbs area of the southern High Plains, Lea County, N. Mex., for the period 1940–60.

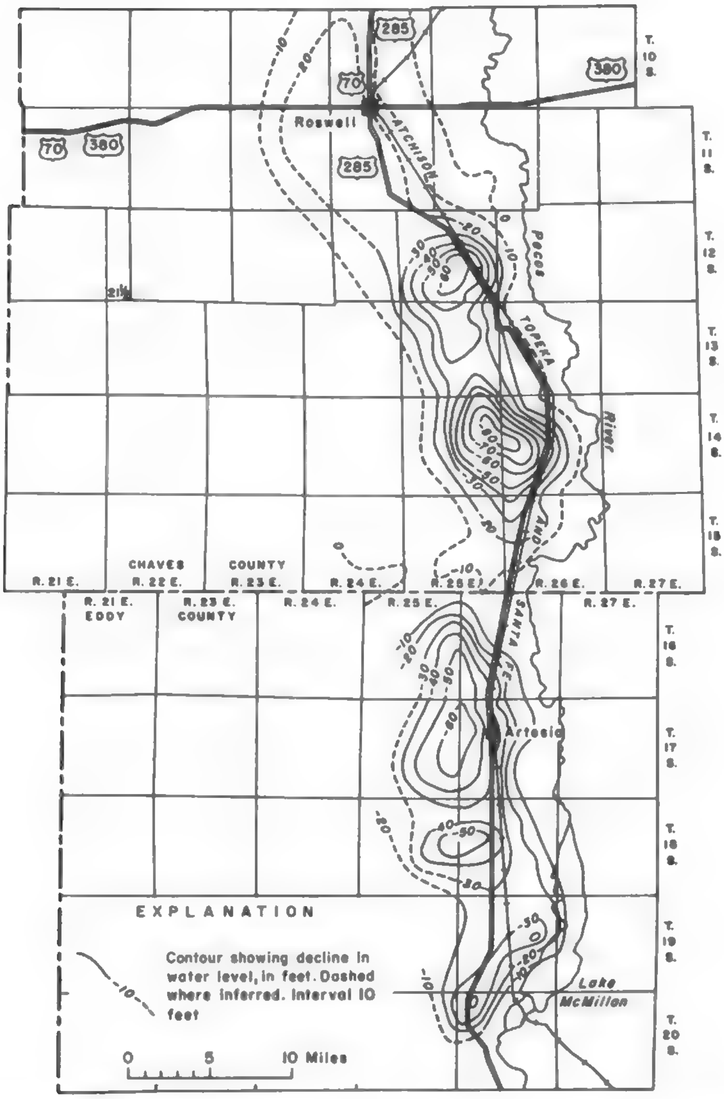


FIGURE 83.—Decline of ground water level in the shallow aquifer in the Roswell basin, Chaves and Eddy Counties, N. Mex., for the period 1938–60.

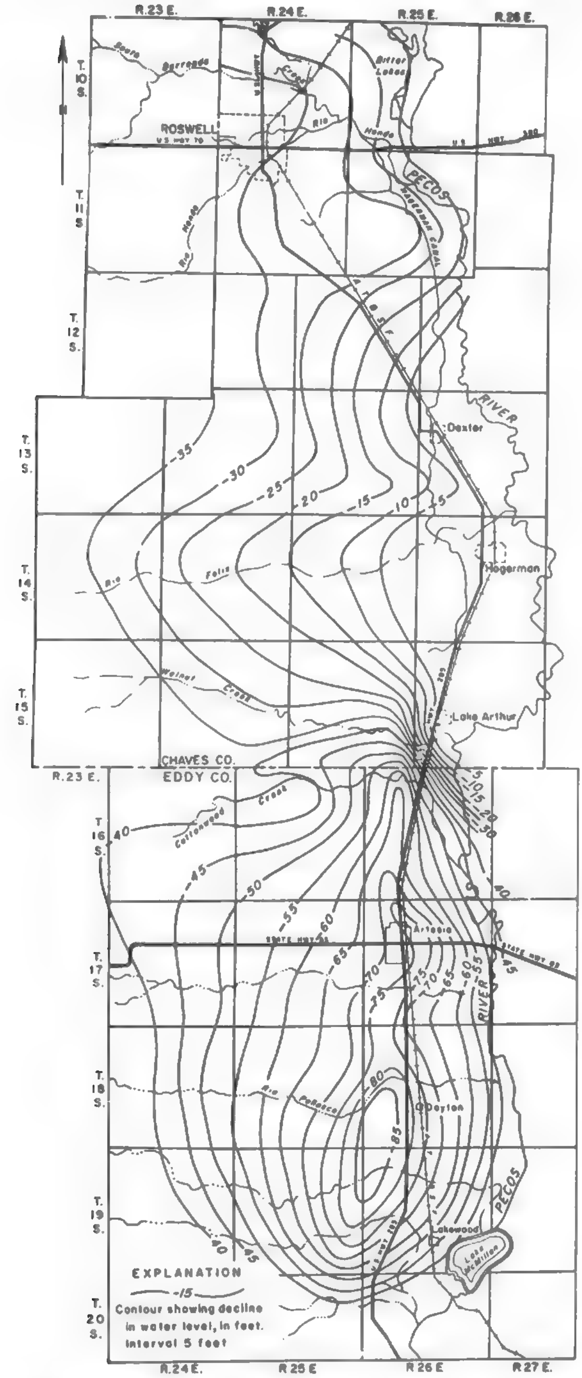


FIGURE 84.—Decline of ground water level in the artesian aquifer in the Roswell basin, Chaves and Eddy Counties, N. Mex., for the period 1944–61.

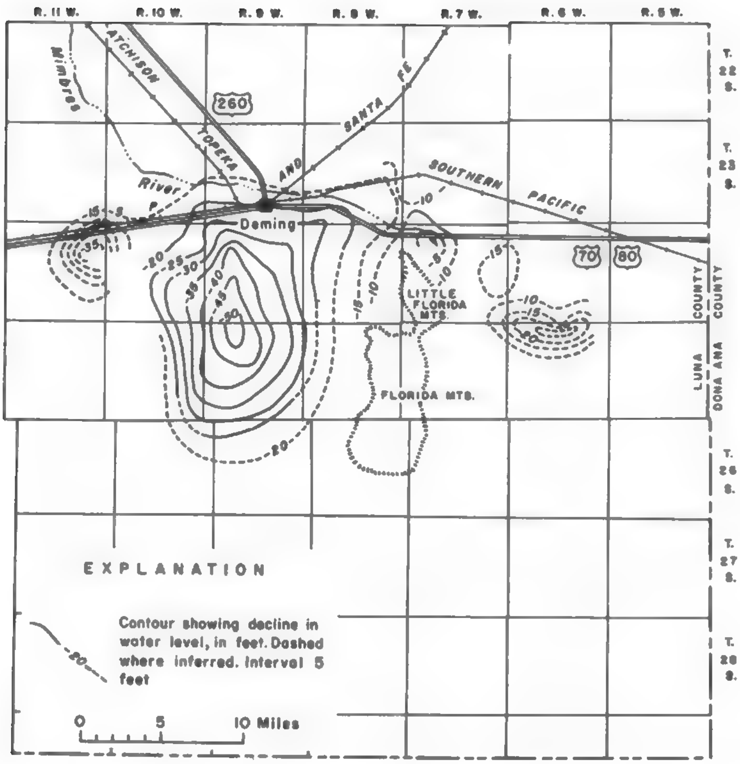


FIGURE 85.—Decline of ground water level in the Mimbres Valley, Luna County, N. Mex., for the period 1940–60.

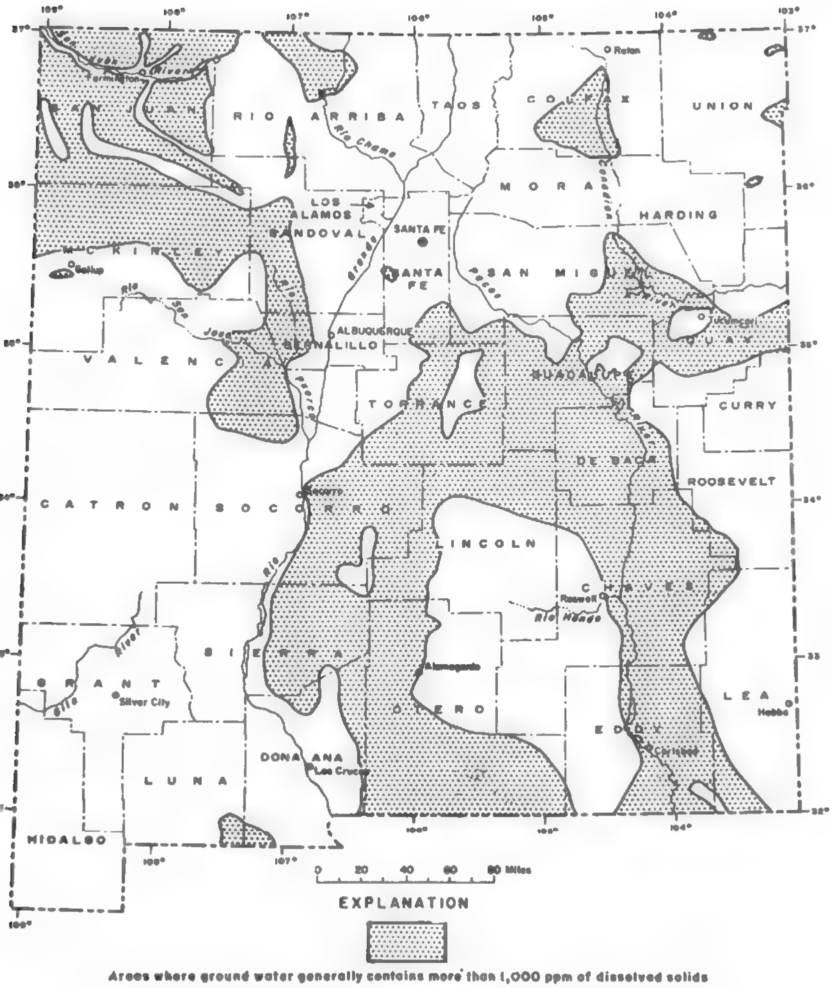


FIGURE 86.—General quality of shallow ground water in New Mexico.

able or is in short supply. Under certain conditions even water classed as moderately saline (3,000 to 10,000 parts per million) is used for irrigation and in industry. Some municipalities and industries have found it necessary to import water of suitable chemical quality long distances through pipelines.

As demands for water increase, and as demineralization of saline water becomes more economical, larger volumes of saline ground water will be consumed and it will become practical to use very saline water (10,000 to 35,000 parts per million) or even brine (over 35,000 parts per million). The first large-scale saline-water conversion plant in New Mexico was put in operation at Roswell in 1963. The plant capacity is about 1 million gallons per day of potable water.

The general concentration of dissolved solids in the shallowest saline water zones in New Mexico is shown in figure 87. In many parts of the State the shallowest saline water underlies a zone of fresh ground water containing less than 1,000 parts per million. Similarly, in many areas the shallowest saline water zone is underlain at greater depth by other saline aquifers.

WATER UTILIZATION

In ancient time pueblo Indians in western New Mexico maintained irrigation works to utilize floodwaters from normally dry streambeds. Drought caused abandonment of many of the pueblos and the Indians settled in the major river valleys, where the water supply was more dependable. The Spanish entered New Mexico about 1600 and settled in the valleys, where they constructed irrigation ditches and dug shallow wells for domestic supply. Most of the water used in New Mexico before 1900 was obtained by diversion from streams.

As the population grew and agriculture expanded, water use increased. The demand for agricultural, domestic, stock, municipal, and industrial water eventually exceeded the surface supply, and the demand has been met in part by developing ground-water supplies.

Irrigation with ground water expanded in some areas, such as the Roswell Basin, the Mimbres Valley, and the Portales Valley, in the late 1920's; the greatest expansion of irrigation in New Mexico began about 1946 and continued through 1956. In 1964, a total of about 1 million acres of land was irrigated in the State, of which about 335,000 acres was irrigated with surface water, 524,000 acres with ground water, and 141,000 acres with a combination of ground and surface water. Figure 88 shows the areas irrigated in 1964 and table 52 lists the acreage irrigated according to source of water in 1964.

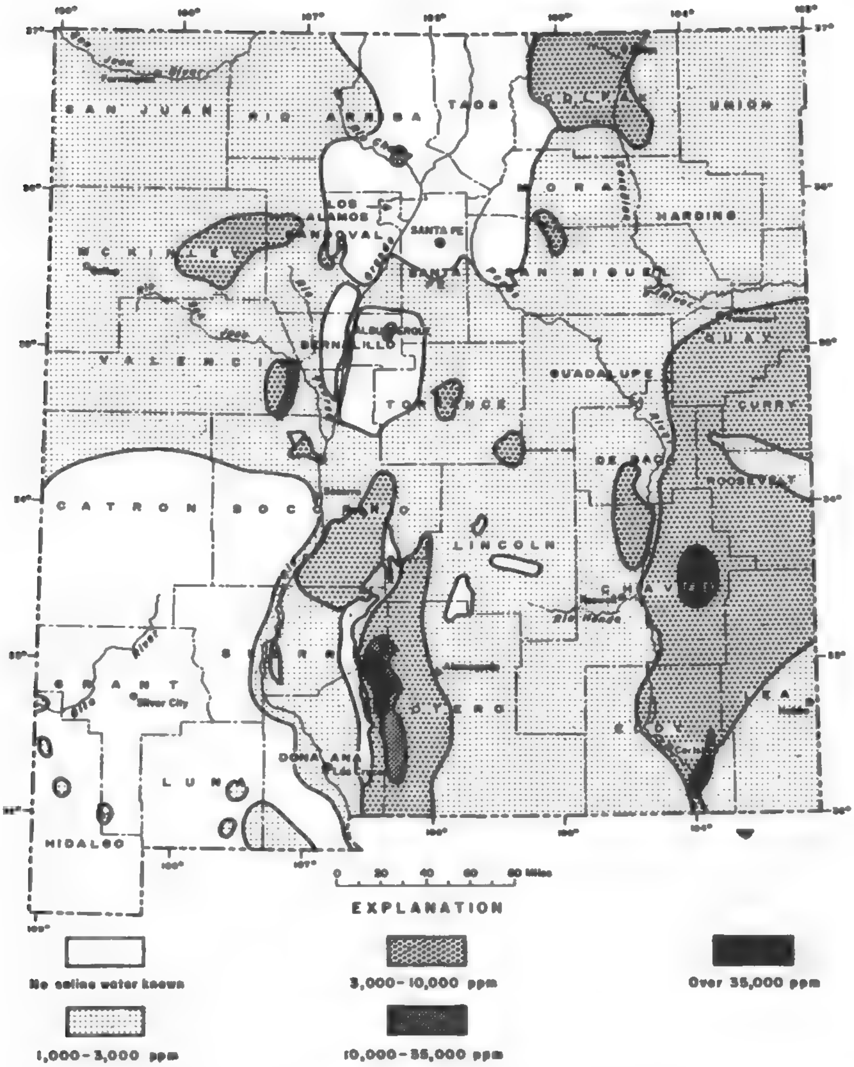


FIGURE 87.—General occurrence of saline ground water in New Mexico.

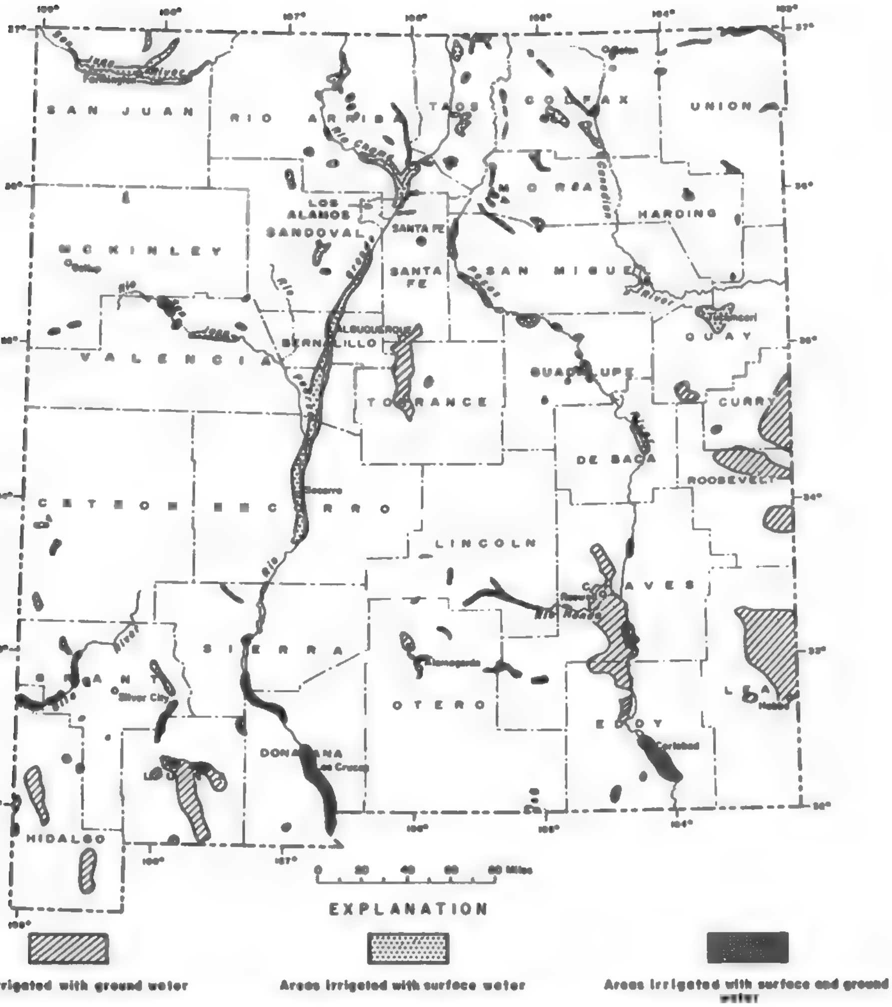


FIGURE 88.—Areas irrigated in New Mexico, 1963.

TABLE 52.—*Acreage irrigated and source of water in New Mexico, 1964*

	Irrigated acreage			
	Surface water only	Surface water supplemented with ground water	Ground water only	Total
Arkansas River Basin	95,130		4,530	99,660
Southern High Plains			288,200	288,200
Pecos River Basin	39,220	32,935	124,405	196,560
Central closed basins	3,070	1,000	28,440	32,510
Rio Grande Basin	132,590	102,530	21,325	256,445
Western closed basins			160	160
San Juan River Basin	51,000			51,000
Lower Colorado River Basin	13,780	3,950	3,540	21,270
Southwestern closed basins	215	1,000	53,220	54,435
State total	335,005	141,415	523,820	1,000,240

NOTE.—Compiled by Earl Sorenson, New Mexico State Engineer Office.

The need for water for public supply is increasing as the urban population increases. The urban dweller has little interest in agriculture, but he desires water for landscaping and recreation. Water diverted for public supply in 1962 was 111,000 acre-feet (table 53).

TABLE 53.—*Diversion and source of water other than for irrigation in New Mexico, 1962 (estimated)*

	Ground water (m.g.d.)	Surface water (m.g.d.)	Total (m.g.d.)	Total (acre-feet per year)
Public supply	90.2	8.9	99.1	111,000
Industrial, self supplied	41.0	7.2	48.2	54,000
Fuel-electric power	2.5	15.4	17.9	20,000
Rural domestic	8.2	2.5	10.7	12,000
Livestock	7.2	7.1	14.3	16,000
Total	153.4	36.8	190.2	213,000

Use of water in industry has increased significantly as industry has become more diversified. Diversion of self-supplied water for industry in the State was estimated to be 26,000 acre-feet in 1955 but had increased to 74,000 acre-feet in 1962.

The New Mexico mineral industry alone used about 16 billion gallons (49,000 acre-feet) of new water (water used for the first time in an operation) and reused 152 billion gallons (465,000 acre-feet), a total usage of 168 billion gallons (515,000 acre-feet) in 1962. Consumption amounted to 7.6 billion gallons (23,000 acre-feet) (table 54).

TABLE 54.—*Mineral production and water usage in New Mexico mineral industries, 1962 (major water users)*

[After Gilkey and Stotelmeyer, in press]

Industry	Production	Production value (thousands of dollars)	New water (millions of gallons)	Reused water (recirculated and transferred) (millions of gallons)	Total usage (new, recirculated, and transferred) (millions of gallons)	Total usage per unit of production (gallons)	Consumption (millions of gallons)
Potash	2,208,000 tons (K_2O equivalent)	85,124	5,333.8	33,886.4	39,220.2	17,800 per ton of K_2O equivalent.[1]	2,407.8
Uranium	3,478,238 tons of ore [2] (3,570,127 tons processed).[3]	63,504	1,515.5	26.4	1,541.9	430 per ton of ore	1,014.8
Copper	165,366,000 pounds [4]	50,933	2,826.7	22,136.8	24,963.5	150 per pound of copper [5]	1,734.5
Lead-zinc	46,298,000 pounds [4]	5,272	268.6	31.8	300.4	6.5 per pound of lead, zinc	64.2
Sand and gravel	1,044,100 tons (wet process)	1,302	309.3	157.3	466.6	447 per ton of product	47.0
	5,844,900 (dry process)	6,719	4.0		4.0		[6] 2.0
Cement	([7])	([7])	9.5	795.2	804.7		8.4
Coal	677,000 tons	2,596	29.2	262.1	291.3	430 per ton of product [8]	14.7
Oil and gas well drilling	8,593,900 feet drilled		485.1	([9])	485.1		[6] 50.0
Petroleum, secondary recovery	9,519,128 barrels	26,399	[10] 2,256.6		2,256.6	235 per barrel of oil	([11])
Natural gas processing	935,299,000 gallons of liquids	37,135	2,743.4	94,464.3	97,207.7	137 per 1,000 cubic feet (throughput).[13]	2,170.6
	655,000,000,000 cubic feet of residual gas.[12]						
Do	27,377,000 cubic feet of helium	958	19.4	408.4	427.8	15,600 per 1,000 cubic feet (helium).	18.4
Do	67,706,000 pounds of carbon black	5,330	120.4	105.1	225.5	3.3 per pound of carbon black.	104.6
Total		([14])	15,921.5	152,278.8	168,195.3		7,637.0

[1] Excluding water used in power generation, this figure would be about 13,600 gallons per ton.
[2] Ore mined in New Mexico (about 5,800 tons of this was not processed in New Mexico).
[3] Includes some ore from out of State.
[4] Recoverable content of ores, etc.
[5] Excluding water used in power generation, this figure would be about 33 gallons per pound.
[6] Estimate.
[7] Figure withheld to avoid disclosure of individual company data.
[8] Of the 677,000 tons total production, only 251,670 tons was washed. (Total water usage at the 1 washing plant is 1,060 gallons per ton of washed product.)
[9] Recycling of drilling mud is not considered "recirculation" as defined in this report.
[10] Possibly includes some recirculated water.
[11] Negligible.
[12] Includes 593,000,000,000 cubic feet returned to pipelines, valued at 21 cents per 1,000 cubic feet at "point of consumption."
[13] Excluding water used in power generation, this figure would be about 130 gallons per 1,000 cubic feet of throughput.
[14] Value of all mineral production in New Mexico in 1962 was $674,100,000. This includes $313,100,000 for crude oil and $92,500,000 for natural gas (wellhead values).

Of the 16 billion gallons of new water, 11.9 billion gallons (36,500 acre-feet) was "self-supplied" from ground water sources, and 2.6 billion gallons (8,000 acre-feet) was "self-supplied" from surface sources. Approximately 1.5 billion gallons (4,500 acre-feet) was purchased. Some of the water from company-owned wells is piped as far as 30 miles. Rural, domestic, and stock use of water has increased slowly and in 1962 amounted to 28,000 acre-feet.

Types of recreation that require bodies of open water are increasing; notably, water skiing, boating, and fishing. A great increase in tourism, camping, and numbers of swimming pools have added to the competition for water, commonly at places where previous demands have been small.

Future needs for water in the State are speculative. When increased demand for municipal, industrial, and recreation water becomes larger than the unappropriated water supply at the locations of demand, such demand can be satisfied by acquisition and transfer of rights, accompanied by a decrease in use of water for agriculture. Though the effective water supply might be increased in many areas by weather modification, artificial recharge, salvage of water lost to evapotranspiration, and better conservation, these practices may not provide the water required for municipal, industrial, and recreational uses. In parts of the State, mining of water can be practiced for a time, and water might be transported from areas of plenty to areas of shortage. In some areas and for some uses, present deposits of saline water may be feasibly desalinized.

By the year 2000 Albuquerque may have a population of 800,000 to 1 million and require 160,000 to 200,000 acre-feet of water annually, part of which will be returned to the Rio Grande. If other towns increase in the same proportion, the total needs for municipal supply may be of the order of 500,000 acre-feet annually.

Projection of the 1962 water requirements of the mineral industry indicates that the total demand for new water will increase from the 16 billion gallons used in 1962 to 24 billion gallons (74,000 acre-feet) in 1980, a 50-percent increase; and to 36 billion gallons (110,000 acre-feet) in 2000, which is 125 percent more than the 1962 intake of new water (table 55). The total industrial need may reach 500,000 acre-feet in the year 2000.

Part of this need may be met by development of natural steam. Drilling in certain volcanic terranes of New Mexico has indicated that natural steam which could be used for electrical power generation may be available at shallow depths. Several thermal areas are known, but none have been adequately explored or developed.

The use of water for rural domestic and stock supply is not expected to increase significantly. Water to enhance recreation may require an additional 200,000 to 300,000 acre-feet annually.

Legal control of water use has been exercised in New Mexico since the days of Spanish colonists. The Spanish made land grants to many individuals and to the Indian pueblos and water rights accompanied the land grants. Thus, water rights and the doctrine of prior appropriation were established at an early date in New Mexico.

Interstate compacts regulate deliveries to and from New Mexico of water in most of the major streams. These compacts include the Colorado River (1922), La Plata River (1922), Rio Grande (1938), Costilla Creek (1944), Upper Colorado River (1948), Pecos River (1948), and Canadian River (1950).

TABLE 55.—*Water requirements for New Mexico mineral industries in 1962, 1980, and 2000*

[After Gilkey and Stotelmeyer, in press]

Industry	Production, 1962	New water,[1] 1962 (millions of gallons)	Estimated production, 1980	New water,[1] 1980 (millions of gallons)	Estimated production, 2000	New water,[1] 2000 (millions of gallons)
Potash	2,200,000 tons of K_2O equivalent	5,333.8	2,300,000 tons of K_2O equivalent	5,563	2,300,009 tons of K_2O equivalent	5,563
Uranium	3,500,000 tons of ore	1,515.5	3,500,000 tons of ore	1,515	3,500,000 tons of ore	1,515
Copper	165,000,000 pounds	2,826.7	260,000,000 pounds	3,850	260,000,000 pounds	3,850
Lead-zinc	46,000,000 pounds	268.6	46,000,000 pounds	268	46,000,000 pounds	268
Molybdenum	([2])	([2])	3,000,000 tons of ore	800	3,000,000 tons of ore	800
Sand and gravel	6,900,000 tons	312.3	25,000,000 tons	1,140	59,000,000 tons	2,680
Cement	([2])	9.5		23		50
Coal	677,000 tons	29.2	975,000 tons	42	1,200,000 tons	48
Oil and gas well drilling	8,600,000 feet	485.1	8,600,000 feet	485	8,600,000 feet	485
Petroleum, secondary recovery	9,500,000 barrels	2,256.6	15,900,000 barrels	3,768	29,800,000 barrels	7,086
Natural gas processing	935,000,000 gallons of liquids	2,743.4	2,100,000,000 gallons of liquids	6,233	4,400,000,000 gallons of liquids	12,082
Do	27,000,000 cubic feet of helium	19.4	27,000,000 cubic feet of helium	19	27,000,000 cubic feet of helium	19
Do	68,000,000 pounds of carbon black	120.4	68,000,000 pounds of carbon black	120	68,000,000 pounds of carbon black	120
Total		15,921.5		23,826		36,516

[1] Water used for the first time in an industrial operation.
[2] Not available.

Although much of the water to which New Mexico is entitled under these compacts has been appropriated to beneficial use for many years, new works on the San Juan River under the Colorado River Storage Project Act will make it possible to make beneficial consumptive use of an additional 700,000 acre-feet or more per year of the water to which New Mexico is entitled under the Colorado River compacts.

Works constructed or planned by the New Mexico Interstate Stream Commission on the Canadian River will make possible additional consumptive uses amounting to 60,000 acre-feet or more under the Canadian River compact.

Legislation in 1931 proclaimed ground waters to be public waters, subject to appropriation and control, as are surface waters, and under the administration of the State engineer. The New Mexico code has become a model for water law in other Western States. By 1963 the State engineer had declared 19 underground water basins in New Mexico (fig. 89).

WATERPOWER

(By W. C. Senkpiel, U.S. Geological Survey, Denver, Colo.)

As of December 31, 1962, the State of New Mexico, with an estimated gross theoretical waterpower potential of 433 megawatts (1 megawatt is equal to 1,000 kilowatts or 1 million watts) existing at all its developed and possible but undeveloped sites, ranked 33d in the Nation in capacity of this renewable resource. This aggregate value is slightly more than one-third of 1 percent of the U.S. total, whose theoretical potential was then estimated to be 121,346 megawatts. These two estimates (Young, 1964, table 10) are based on all arithmetic mean streamflows of record through 1962. New Mexico ranked only 43d among the States in installed nameplate (manufacturers' nameplate rating of generators) capacity, with the 24.3 megawatts in service at its only developed hydropower site, Elephant Butte Dam, Sierra County. This installation represented one-sixteenth of 1 percent of the national nameplate total of 38,600 megawatts at the end of 1962 (Young, 1964, table 10) .

The gross theoretical waterpower in New Mexico is summarized by principal drainage areas and subdivisions (table 56). The data given therein have been evaluated essentially in accordance with standards established by the World Power Conference. These standards assume utilization of the total existing head at 100-percent efficiency for streamflows available 95 percent of the time (Q-95) and 50 percent of the time (Q-50) and for the arithmetic mean flow (Q-mean). The tabulation includes the theoretical hydropower potential at all developed sites regardless of size and of all undeveloped sites having a total potential of at least 1 megawatt or half a megawatt per mile of stream at Q-50.

The 95-percent power based on Q-95 represents the approximate dependable potential of streams lacking storage capacity for regulating and equalizing their variable flows. This value today does not have the significance that it had in the early days of hydropower development, for several reasons. Most operations now depend on flow regulated by storage rather than on natural streamflow. The early developed projects were generally single installations whereas, at present,

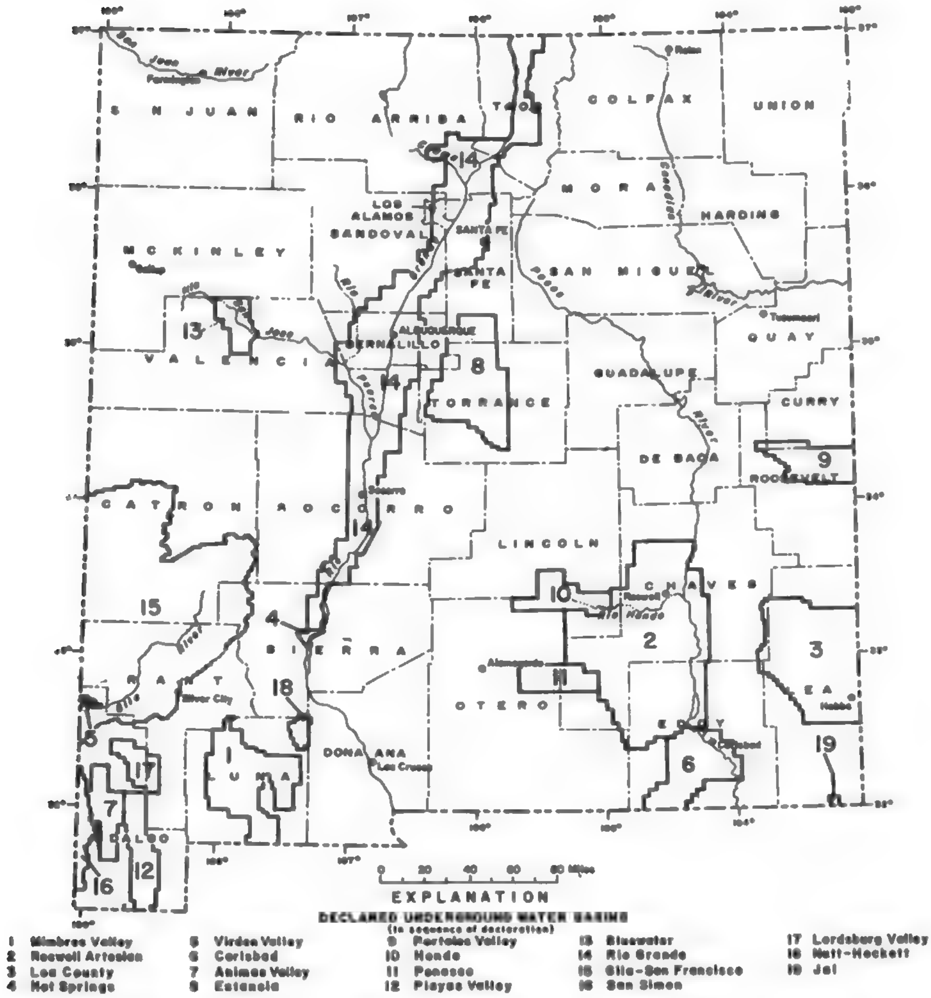


FIGURE 89.—Underground water basins in New Mexico, as declared by the State engineer, as of December 1963.

TABLE 56.—*Developed and undeveloped waterpower in New Mexico, Dec. 31, 1962*

[MW.=1,000 kilowatts]

Principal drainage areas and subdivisions	Drainage basin index No.	Developed waterpower sites: Number of sites	Developed: Gross theoretical power (MW.), gross head, 100 percent efficiency, and flows at— Q-95	Q-50	Q-mean	Developed: Installed capacity (MW.)	Undeveloped waterpower sites: Number of sites	Undeveloped: Gross theoretical power (MW.), grosshead, 100 percent efficiency, and flows at— Q-95	Q-50	Q-mean	Total gross theoretical power (MW), developed and undeveloped sites based on mean flow
Rio Grande Basin	8-B						9	27.3	66.3	119.2	119.2
Do	8-C	1	0.1	17.7	17.1	24.3	1	.01	5.0	6.1	23.2
Total, Rio Grande Basin		1	.1	17.7	17.1	24.3	10	27.31	71.3	125.3	142.4
Colorado River Basin:											
San Juan River Basin	9-G						4	39.1	109.8	286.0	286.0
Gila River Basin	9-M						2	1	2.5	4.6	4.6
Total, Colorado River Basin							6	40.1	112.3	290.6	290.6
Total for State		1	.1	17.7	17.1	24.3	16	67.41	183.6	415.9	433.0

most of them are interconnected into a large system of which the characteristics of streamflow and storage are such that deficiencies in any one area can readily be absorbed by other units of the system. The principal worth of the Q-95 evaluation is for comparative purposes, nationally as well as internationally. It also indicates, in general, the minimum power potential of any stream or area under consideration.

Evaluations of the potential based on Q-mean, which represents the maximum attainable power: tend to give higher values than can generally be realized. To achieve this condition sufficient storage must be available to regulate streamflow so that all the water, including floodflows, passes through the turbines. Such complete equalization is seldom obtained because of the absence of topographically or geologically feasible damsites, lack of adequate storage capacity, or the higher use of the water for industrial or agricultural purposes.

As previously stated, these evaluations are based on 100 percent efficiency, which is in accordance with World Power Conference recommendations. Experience has shown that the overall efficiency for a hydropower project will vary between 75 and 85 percent.

The inability to operate storage reservoirs effectively for both irrigation use and power generation has retarded the growth of hydropower development in New Mexico. This situation is confirmed by the existence of only one developed installation. This project, with an installed nameplate capacity of 24.3 megawatts (three units of 8.1 megawatts each) is a Bureau of Reclamation powerplant at Elephant Butte Dam on the Rio Grande at a site located 4 miles east of the town of Truth or Consequences, N. Mex. The dam was completed in 1916 and the plant was added in 1940. The reservoir created by this 301-foot-high (structural height) concrete gravity dam can store about 2,200,000 acre-feet of usable water, when available, for year-round generation of power and downstream irrigation purposes. The powerplant is operated by the Bureau on a schedule governed by water releases for irrigation. The average annual output of the plant has been estimated by several sources to be between 90,000 and 96,000 megawatt-hours. According to the Federal Power Commission's monthly summaries, Electric Power Statistics, the energy production of the plant in calendar years 1962 and 1963 was 63,746 and 43,662 megawatt-hours respectively. The year of lowest output appears to have been fiscal 1955, according to the Bureau's records. During this very dry period only 7,078 megawatt-hours were generated.

Almost two-thirds of the gross theoretical hydropower potential in New Mexico is in the San Juan River drainage basin (table 56) because of the large streamflows available there. However, only one of the four possible powersites in the basin appears to be economically feasible. This is the recently completed Navajo Dam on the main stem, for which an onsite installed capacity of 30 megawatts has been suggested by the Bureau of Reclamation. Nearly all the remaining potential occurs in the upper Rio Grande drainage basin where streamflow and topography seem favorable for power development.

Possibilities for future hydropower development are limited by the competition for available water supplies and the priorities already established by present uses, especially for irrigation. The importance of this incompatability of interest is reflected by the Colorado River Storage Project Act which states: "That with reference to the plans

and specifications for the San Juan-Chama project, the storage for control and regulation of water imported from the San Juan River shall (1) be limited to a single offstream dam and reservoir on a tributary of the Chama River, (2) be used solely for control and regulation and no power facilities shall be established, installed or operated thereat * * *." There will, however, be excellent opportunities for peaking power generation by means of pumped storage sites in the State. New Mexico will also receive its share of the energy generated at Glen Canyon Dam in Arizona and at other multipurpose units of the Colorado River storage project.

According to the Federal Power Commission there were 30 electric generating plants in New Mexico at the end of 1962, with a total installed nameplate capacity of 947.3 megawatts. Of this total, 24.3 megawatts, or 3 percent, were in service at 1 waterpower plant; 46.9 megawatts, or 5 percent, at 14 internal combustion plants; and 876.1 megawatts, or 92 percent, at 15 steamplants. Because of the large deposits of coal in the State, coal-fired steamplants are the principal source of its electric energy.

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